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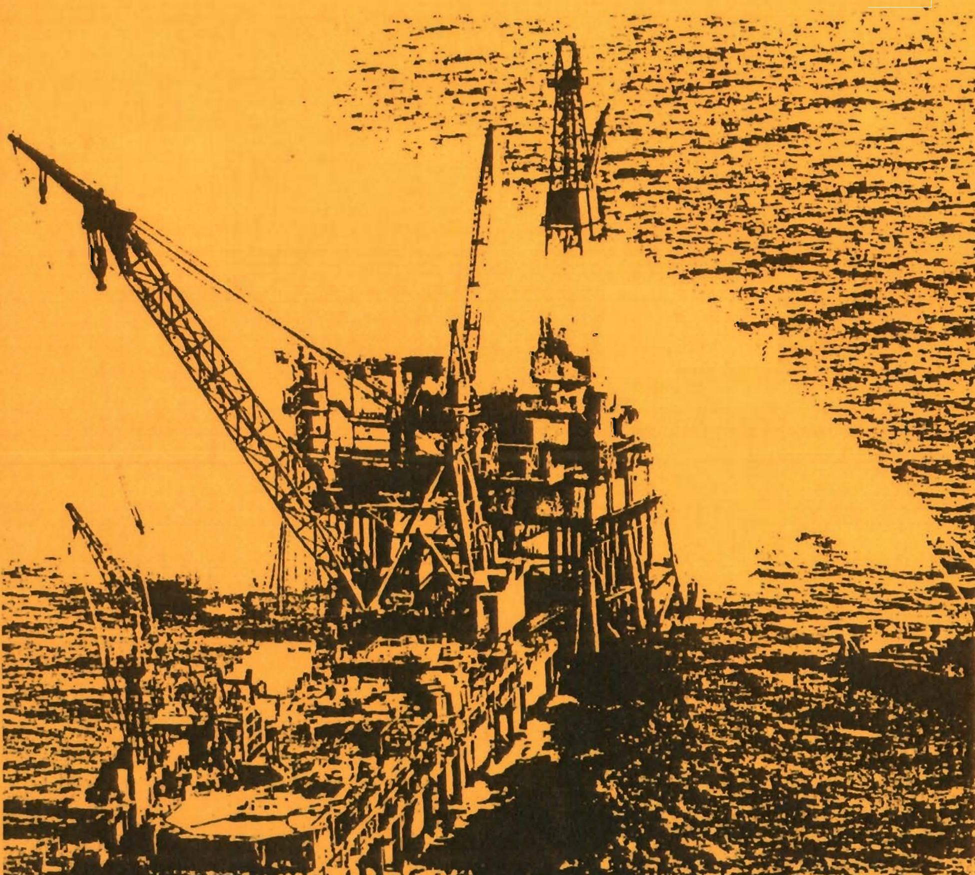
Managing Technological Accidents: Two Blowouts in the North Sea

Incorporating the Proceedings of an IIASA Workshop on Blowout Management

D. W. Fischer, Editor



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MANAGING TECHNOLOGICAL ACCIDENTS: TWO BLOWOUTS IN THE NORTH SEA

Incorporating the Proceedings of an IIASA Workshop on
Blowout Management, April 1978

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For Lynne, Lucy, and Jeff

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PREFACE

For some time before April 1977 I had been studying environmental and development issues in the North Sea. During this research I was told by both industry and government agencies that blowouts of oil and gas wells in the area were "impossible today".

Thus, when the serious blowout occurred at the Bravo Platform, Ekofisk Field, in the Norwegian sector on April 22, 1977, it was clearly an event of vital significance, not only for those directly involved, but also for the work on which I was engaged. Since the contacts and cooperation generated in my earlier work offered me a unique opportunity to follow this event and its consequences within the Norwegian Government and the North Sea oil industry, I did so. Those directly involved extended the cooperation required and I was able to interview key persons in the Norwegian Action Command that had been directly involved in responding to the Bravo blowout.

Less than six months later, on October 14, 1977, a second blowout occurred, this time at the Maersk Explorer Platform off the coast of Denmark. Again, the necessary cooperation was extended and I was able to interview the officials responsible in Denmark.

Under the aegis of the International Institute for Applied Systems Analysis (IIASA), a workshop on blowout management was organized, using these two incidents as the point of departure for the discussion. Widespread interest was shown, and representatives of both industry and government from the United Kingdom and Norway, as well as from other North Sea countries, Canada, and the United States, attended the meeting. The workshop was supported financially by IIASA and technically by the Norwegian Petroleum Society, this latter body being interested in promoting and disseminating practical information and research results to its membership.

This volume started out as an account of the proceedings of the workshop. However, in addition (in Part One), I have myself contributed five chapters. Four of these give an overview of the North Sea blowout problem, descriptions of each of the blowouts, and the issues raised by the participants in the workshop. Furthermore, since the Three Mile Island nuclear accident occurred while this book was being prepared for the press, I was able to add a short chapter drawing attention to some striking parallels between the TMI accident and the Bravo blowout.

Part Two of the book (Chapters 6–10) contains the papers that were presented at the workshop. Several participants did not present formal papers but I considered it valuable to include outlines of their remarks, since they represent authoritative expressions of the views of experts with significant relevant experience.

In this way, through the overviews in Part One and the expert statements based on first-hand experience in Part Two, the book presents a major body of factual and evaluative material on the North Sea blowout problem. It is written for persons with special technical and managerial interests in the blowout problem, as well as for others who may want an overview supported by a significant body of technical detail and authoritative references. In addition, persons interested in technological hazards and associated management issues should also find relevant material in this book.

Any success this effort may have achieved is due entirely to the many people who supported it, including those interviewed and those contributing to and attending our workshop. Hans-Christian Bugge, who was the Director of the Norwegian Action Command at Bravo, was a gracious friend throughout the course of the project: to him I owe a sincere debt of appreciation. Others who gave their time include Dag Meier-Hansen, Torvald Sande, Paul Hofseth, Bjørn Myklatun, Peter Steen, and Tony Read; to all of these men I say thanks. Rolfe Tomlinson at IIASA gave both this project and the overall disaster-management research task his enthusiasm and support. Finally, Shari Howell at IIASA acted as friend, secretary, and workshop coordinator, and I speak for all the workshop participants in extending our thanks to her.

David W. Fischer

INTRODUCTION

David W. Fischer

In 1977 two major offshore blowouts occurred in the North Sea: an oil well in the Norwegian sector on April 22 and a gas well in the Danish sector on October 14. These two near-disastrous events signaled that such blowouts could no longer be dismissed. Up to this time the occurrence of such events in the North Sea was seen as "impossible" by both the oil industry and its regulators because of innovations in prevention technology and the high safety requirements specified. Such optimism is not hard to understand given the record of drilling operations in the North Sea that existed before these accidents as noted by Cooper and Gaskell [1] in 1976:

> "The North Sea, being the most inclement offshore oil area, has seen the greatest development in safety measures for offshore work. Every year better blowout preventers and automatic chokes to shut down wells in case of accident are designed. Each accident is fully investigated to see where better codes of practice can be devised."

Thus, the two major blowouts of 1977 were greeted with surprise and generated an awareness of the need for even greater preventive and safety measures.

A blowout is the result of a sudden uncontrolled release of gas or gas–oil at extremely high pressure. This unexpected high-pressure release occurs at great velocity and the large amounts of material evolved are at a high temperature. Hence, the risks of explosion, fire, and widespread pollution are all present. Blowouts represent the potential loss of life and equipment, as well as loss of the gas or gas–oil itself together with the associated revenue and energy content.

Blowouts can occur on drilling into an unexpectedly high geological pressure zone, from human error, equipment failure, or external causes such as collision or fire. The possibility of a blowout exists at all drilling stages (whether for exploration or production), during production, and during maintenance and inspection of the drilling and production equipment.

This book describes the system within which the blowouts occurred and summarizes post-1977 thinking by both the oil industry and its government regulators. It does not attempt to find fault with either industry or government; nor does it provide a technical description of the two blowouts that occurred. Rather, it aims to place the blowouts in the larger framework of disaster management. This means that blowouts are viewed as examples of an important man–technology interface with a potential for disastrous consequences, thus demanding a broad range of management skills.

This is a particularly valuable means of viewing blowouts because of the general overview it requires. Frequently, in both industry and government, a holistic view is difficult to obtain. For example, in the present cases, various departments within firms, various subcontractors, and several regulators were involved in the design, approval, construction, operation, maintenance, and investigation of drilling and the production platforms. Any one group is so specialized that it is usually not competent to investigate the overall process of introducing and operating an offshore platform. In addition, a group organized to investigate a major accident such as a blowout often has difficulty in obtaining the necessary overview through lack of specialized knowledge, severe time constraints, and the fact that the investigation is limited to one incident only.

The potential for the occurrence of technological or man-induced disasters has increased as the pace and scale of new technological operations have accelerated throughout the world. The production of hazardous materials and the operation of hazardous technologies in hazardous locations account for the growing interest and concern in mitigating or managing the effects of accidents. Research is increasingly being devoted to studying technological hazards [2].

Because many technological disasters are one-time events of low probability, they are only briefly considered by the large numbers of workers, supervisors, regulators, users, and third parties in the industry who are not directly involved with the accident. Even the disastrous consequences of such low-probability disasters fail to maintain the active interest of these groups in the long term. In addition, the behavior of the social groups directly involved with or affected by disaster are not always common [3].

A blowout is an example of a complex technological process that has gone out of control in a hazardous environment; as such it shares many attributes of other technological disasters. However, blowouts can induce changes in worker behavior, operational and organizational conditions, technological safeguards, and recovery mechanisms because of the immense financial value of oil and gas resources, to the operator and to the regulating government. In addition, the regulator places stringent rules and liability conditions on the operator, who is entirely in control of the offshore platform. These financial considerations and controls act as strong inducements to implement advantageous changes in operation techniques and technological development. Finally, social demands for governments to control the actual or potential oil pollution of shorelines also brings about changes in operating conditions, not only on offshore platforms alone, but also in test sites open for drilling, and this can even affect the overall environmental controls of entire societies [4].

Blowouts and other technological disasters share a number of attributes: they are low-probability, high-consequence events; actual experiences are limited and discontinuous; they involve technologies with highly integrated subsystems; changes in technology and transfers in manpower are frequent; a large number of operations and organizations exist; and hazardous operating environments are involved. These attributes contribute to the blowout potential associated with all offshore drilling and production platforms. Such platforms are highly complex entities with many individual wells being drilled, producing, or being maintained at any particular time. Spacing is one of the most widely accepted means for reducing the consequences of technological disasters. Yet an offshore platform is so compact and so many activities are carried out one upon another that such a spacing program is impossible. This book does not attempt to provide an in-depth survey of offshore platforms; the interested general reader can find such a survey elsewhere [5]. Large numbers of organizations are involved in constructing, operating, and maintaining platforms. The myriad of subcontractors, subsubcontractors, and workers of different nationalities used at different stages can jeopardize safety because of different attitudes toward risk and differing views of the overall system.

Two attributes of blowouts that are not shared with other technological disasters are the uncertainties of environmental conditions and impacts. An offshore platform as designed, constructed, towed, located, and operated is subject to uncertain environmental forces, such as heavy storms with high winds and waves, deep waters, shifts in the seabed, and high-pressure collapsible geological structures. These forces can cause the platform to sink, collapse, corrode, and blow off location, thus generating blowouts via the sheared wells. In addition, ships can collide with a platform in conditions of poor visibility or because of bad seamanship or failures in radar and communications [6]. None of these events is wholly predictable, and the year of 1977 showed that blowout risk could no longer be ignored in the North Sea. Technological processes normally operate in known environmental conditions, so that safe operation is more or less assured. Only space technologies appear to surpass offshore platforms in the number of unknowns that have to be taken into account during design and operation. In this sense, it is a tribute to the oil industry and its regulators that major offshore accidents have been so few.

The second attribute arises because of the uncertain long-term environmental effects of spilled oil in the ocean and along the shore. The oil industry has frequently noted that natural underwater seepages from undrilled offshore reservoirs release a much larger amount of oil than has ever been evolved from a blowout [7]. Natural seepage is a constant source of small, diffuse emissions over a wide area, while the impacts of a blowout are sudden, massive, and highly concentrated at the source. Thus although the impact of a blowout can affect the immediate marine environment, the extent of this influence is at present unknown in the long term. Therefore, the upper limit of the cost of controlling oil pollution from a blowout is also unknown. At present every effort is exerted to reduce oil pollution, whether from tanker spills or blowouts. Inducements for this effort are the indirect effects of blowouts, including political strain on the government, bad publicity for oil industry, and public reaction, all of which can lead to conflict over oil-related projects elsewhere, even at a much later date [8].

From the foregoing it is clear that a blowout is a significant event. The two major blowouts in the North Sea were without precedent at the time, and many of the lessons learned have been incorporated in present practice. This book does not detail these changes; rather, it seeks to give an overview of the blowout problem that will be useful in assessing optimum response, regardless of specific changes in technology and operations.

This book is in two parts: the first offers an overview of the blowout problem; the second supports this view by reports from the proceedings of the IIASA workshop on blowouts. For good and obvious reasons, both the oil industry and its regulators emphasize the prevention of blowouts. Because of this existing strong emphasis, attention will be focused on the response required to a blowout once it has occurred. Responses of the oil industry and government to actual blowouts are studied here, but only on the basis of the two cases studied in the North Sea. Therefore, this volume is not a complete study of the blowout problem. For a more complete technical survey of blowouts in the North Sea the interested reader is referred to Ref. 9.

The first three chapters give an overview of response to a blowout for the two cases in the North Sea. The first chapter considers the general framework of blowout response in qualitative terms. It outlines in a general way the stages of prevention, well control, and pollution control, with alternatives, on the basis of decision trees. No attempt is made to decide which branch of the decision tree is superior. Rather an overview is preferred in order to provide a context for discussion of the two cases.

The second and third chapters describe the blowout responses in the Norwegian and Danish sectors of the North Sea. Both of these countries are highly sophisticated technically and have strong and abiding interests in safety and antipollution measures. Therefore, the actions taken by Norway and Denmark before, during, and immediately after their blowouts are of general interest. The second chapter is devoted to the blowout in the Norwegian sector, while the third describes the Danish-sector blowout and compares it to the Norwegian-sector event.

A fourth chapter describes the experience gained from a very different type of accident – that at the Three Mile Island nuclear facility – where nevertheless many of the same issues were raised. This chapter provides a comparative overview of the Ekofisk Bravo and Three Mile Island accidents from an organizational standpoint in the hope of providing a more coherent organizational form for managing future technological accidents.

The fifth chapter contains a summary of the main points in the papers presented at the IIASA workshop and an overview of the issues emerging from the workshop discussions. The participants were selected on the basis of nationality, employer, and their position with respect to blowout-response systems. Norwegian and British oil-industry representatives, regulators, and environmental experts were present and made major contributions to the meeting. In addition, US and Canadian government representatives added their experiences as a contrast to the North Sea experiences. Finally, some other North Sea countries also made contributions. The discussions were particularly valuable in highlighting issues of importance in blowout response and the prevention of future blowouts.

The second part of the book (Chapters 6–10) contains the papers presented at the workshop. In some cases, where no formal paper was presented, an outline is included based upon the transcribed recordings of the statements. Each paper has been edited to reduce its size and to emphasize specific points of view.

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1 B. Cooper and T.F. Gaskell, The Adventure of North Sea Oil, Heinemann, London, 1976, p. 135.

2 R.W. Kates (editor), Managing Technological Hazard: Research Needs and Opportunities, Institute of Behavioral Science, University of Colorado: Boulder, 1977; E.W. Lawless, Technology and Social Shock, Rutgers University Press, New Brunswick, New Jersey, 1977. Each of these books represents a different approach to the subject: the Kates book is a theoretical treatment which looks to the future while the Lawless book is a series of diverse case studies with historical emphasis. Both books emphasize the need for an overview.

3 See, for example, the observations with respect to natural hazard in I. Burton, R.W. Kates, and G.F. White, The Environment as Hazard, Oxford University Press, New York, 1978, pp. 205, 211.

4 E.W. Lawless, Technology and Social Shock, Rutgers University Press, New Brunswick, New Jersey, 1977, pp. 243, 244. The Santa Barbara blowout is reported to have led directly to the growth of federal involvement and legislation in the USA in the environmental area; for example, the National Environmental Policy Act.

5 B. Cooper and T.F. Gaskell, The Adventure of North Sea Oil, Heinemann, London, 1976; I.L. White et al., North Sea Oil and Gas, University of Oklahoma Press, Norman, Oklahoma, 1973; J.K. Klitz, North Sea Oil: Resource Requirements for Development of the U.K. Sector, Pergamon Press, Oxford, 1980.

6 See, for example, the list of accidents to North Sea platforms contained in appendix C of I.L. White et al., North Sea Oil and Gas, University of Oklahoma Press, Norman, Oklahoma, 1973, pp. 167–169. Also note, Keeping Oil Tankers Safely Afloat, The Economist, November 4, 1978, pp. 70,71.

7 See, for example, the paper by T.F. Gaskell, Sea Floor Development, Moving into Deeper Water: Environmental Pollution in Offshore Operations, E and P Forum, London, 1977; E.W. Mertens and R.C. Allred, Impact of Oil Operations on the Aquatic Environment, paper by the American Petroleum Institute for UNEP Seminar with Petroleum Industry, Paris, March 1977.

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Part One

Review of the Blowout Problem

1 AN OVERVIEW OF THE NORTH SEA BLOWOUT PROBLEM

David W. Fischer

This chapter reviews the blowout problem associated with offshore platforms and presents a general qualitative framework for the comprehensive management of such a blowout. The prevention of blowouts, the control of wells, and the avoidance of pollution are considered, together with alternative strategies and problems that may be encountered. The importance of striking a balance between resources and risks is discussed as an essential part of blowout management. Finally, the current position toward blowouts in the UK and Norway is addressed briefly.

A GENERAL RESPONSE SYSTEM

The potential for blowouts in the North Sea is considered high enough by both industry and government to justify the expenditure of a great deal of effort and money on preventive measures [1]. One estimate showed that fire-fighting and safety cost about five percent of the total cost of running a 32-well production platform in the North Sea, a figure equal to the total drilling-equipment cost for the same platform [2]. In 1975 the total cost of constructing a production platform in the North Sea was US $100 225 million [2]. Thus a production system is designed, constructed, and operated with safety in mind.

One does not have to look far to understand the concern for platform safety: offshore production must cope with a hazardous and unfamiliar environment, extreme weather conditions, high-pressure geological structures, a shifting seabed, a large number of resident workers, and relative isolation. Given these difficult operating conditions it is clear that operators must invest heavily in the most advanced techniques for sustained oil and gas production, including blowout prevention. However, even the most sophisticated technological system is subject to malfunction, as well as the effects of human error and adverse external conditions. The operating conditions quoted provide a great challenge to those charged with preventing or containing blowouts.

The measures necessary to prevent or control a blowout and to contain an oil slick are shown in Figure 1.1. This generalized scheme shows the chain of successive stages in blowout management from the initial prevention attempt to the final feedback of information learned from the experience. After each unsuccessful stage, oil has escaped into

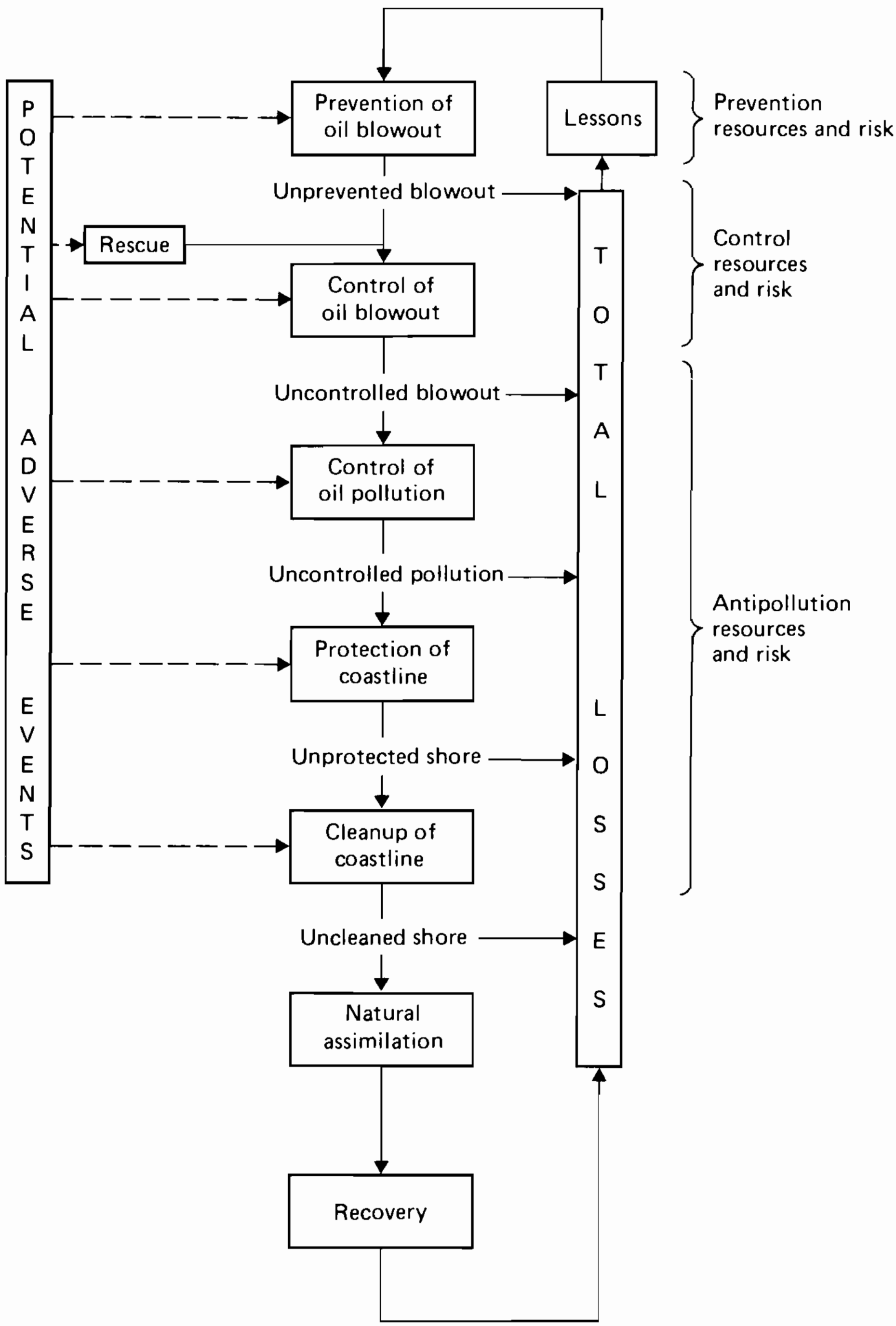

FIGURE 1.1 General oil blowout responses and resources.

the environment and will cause pollution and damage. The amount of oil escaping, with the resulting environmental effects, can be inversely correlated with the resources allocated to each stage to reduce such escape. A blowout program requires the allocation of resources at each stage to prevent or control blowouts and to minimize pollution. Overconcentration of limited resources in a single area can result in uncontrolled release of oil into the environment.

Figure 1.1 shows the general elements of a management system for blowouts. No attempt is made in this figure to show the alternative measures available at each stage. The elements of the system include: prevention of blowouts and rescue; well control; pollution control; implications of resource and risk allocation; adverse events; and the feedback of lessons learned.

The prevention of blowouts is undoubtedly the key element in a management system: prevention is obviously better than containment. Protection of life, of course, has the highest priority when a well goes out of control. When personnel and platform safety is assured, well control becomes of primary importance, since a blowout causes financial loss and pollution, and has political and other economic repercussions. Pollution control requires a major effort to mitigate the effects of oil discharge on both the surface and the underlying water column of the sea. Measures to control the blowout and pollution must be carried on simultaneously.

Resource and risk allocation are important elements because they determine the state of readiness, response, and risk mitigation built into the operation to prevent blowouts and, in the event of an emergency, to contain the blowout and provide rescue and antipollution measures. The financial resources available directly influence the amount of research and development carried out, the introduction of the safest systems available, failsafe mechanisms, standby equipment, and crew training and supervision. The effect of overall resource allocation reduces the inherent risk but there is always some residual risk in the system. A positive approach toward the allocation of resources to reduce risks and an understanding of the implied residual risk at each stage of operation is important if an overall balance in resource and risk allocation is to be achieved. Each offshore platform, as well as each national sector of the North Sea, is subject to a risk that depends on the explicit allocation of the resources made available for preventing and controlling blowouts and their impact; this is so even if the allocation is made in an arbitrary way with no understanding of the overall system and tradeoffs involved.

Adverse events are factors outside the planned functioning of the platform that exacerbate the operating conditions. Indeed, such an adverse event may even cause the blowout in the first place; for example, a sudden shift in the seabed or a marine collision could cause the platform to move and shear the wells. Adverse events can also affect the attempts made to rescue personnel, contain the blowout, and restrict pollution. Resource allocation for blowout prevention and control must take account of the probability of such events.

Feedback is the final important element of Figure 1.1. The experience gained is fed into the system that prevents or responds to blowouts. Of course, resource allocation also affects the degree to which such experience is utilized.

Risk and resource allocation can be a source of conflict. Typically, both the operator of the platform and the regulators view prevention of a blowout to be the prime requirement. This approach is reasonable in that the number of near-blowouts vastly exceeds the number of actual blowouts. However, since the possibility of near-blowouts is very large, preventive measures may exhaust the available resources. Hence practically no resources may be available should a blowout actually occur or to combat other blowout-related events. It is clear that a balanced approach to blowout management requires the allocation of resources to prevent such occurrences and to control unpreventable blowouts. Both of these responses need funds for research, development, design, construction, stockpiling, and training. Resources spent on increasing safety are not reflected in the productivity of the platform and, in some instances, could even reduce it.

To attempt to eliminate blowouts by increasing preventive resources implies, since the overall resources are obviously limited [3] : a decrease in the resources available to combat unpredicted accidents; a decrease in the resources available for productive effort – for example, safety inspectors are substituted for production workers; an increase in the risks of related industries that support, supply, or are otherwise connected with the activity; and an increase in product cost and a decrease in government revenue – preventive measures may slow down production.

An overview often provides a perspective to assess the optimum balance between the potential merits and demerits of a course of action. Excess resources are valuable but can be easily squandered, especially by external pressures after an accident, into ad hoc situations rather than developments based on overall safety considerations. Risk cannot be decreased equally for all activities and, since ever-increasing safety measures are almost always subject to a law of diminishing returns, the productivity of the system is adversely affected.

At any point a decision maker can err by omission or commission. Error by omission includes overlooking risk that could have been anticipated had more resources been available. This implies that resources should be available to cope with any unprevented event. Error by commission is an attempt to anticipate all events by devoting resources to what will never happen. This implies the inability to cope should an unexpected event occur. Obviously, a continuum exists between these two types of error and the actual risk and resource allocation for the system is largely dependent on a series of often disconnected features. Figure 1.1 attempts to show an overall response system for blowouts in which the necessity for achieving a balance between the stages is apparent.

The initial design for a balanced response system based on the framework shown in Figure 1.1 is shown in Table 1.1. This table is a simple layout that can be used for the initial planning and final risk and resource allocation for all the necessary responses to a blowout. More detailed planning is necessary for each of the items noted, but this study emphasizes the overview so that such details are not included here. Each column of Table 1.1 corresponds to the basic stages identified in Figure 1.1, while the rows list the key questions to be answered for each stage in the system. The tabular form allows each stage to be compared to other stages in order to detect risks within the system, and also allows one to total and compare the resources and risks available at each stage with the expected losses during that stage.

A detailed examination of the material needed to answer the questions in Table 1.1 will now be given.

1. What? Objectives for each of the stages are specified and compared, to determine the structure of the response system as a whole.

TABLE 1.1 Planning an oil blowout response system[a].

Questions	Prevention	Rescue and safety	Well control	Pollution control	Recovery	Lessons
What?						
Who?						
When?						
What order?						
How?						
How else?						
With what?						
With whom?						
How long?						
What if?						
What then?						
How much?						
What losses?						
What risk?						

[a]This table was partly compiled from a mimeographed set of notes provided by the Norwegian Petroleum Society, Oslo, 1977.

2. Who? Organizations or participants are identified with each of the objectives above and their known capabilities are compared.
3. When? Optimum timing of the necessary measures is determined by considering the coordination process.
4. What order? The precedence of what is to be done and when can be determined (the priorities) and can be used as the basis for later tradeoffs.
5. How? Actual procedures for accomplishing the above objectives are determined.
6. How else? Alternatives to the above procedures are predetermined, should the planned procedures become unworkable.
7. With what? Resources required for carrying out the necessary procedures and their alternatives are determined.
8. With whom? Other organizations and participants important to each stage are determined and coordinated.
9. How long? The overall timeframe for each stage is computed for stockpiling and deciding priorities.
10. What if? Adverse events that could occur and influence planned responses are determined.
11. What then? Changes in planning necessitated by such adverse events are taken into account for greater flexibility.
12. How much? The total cost of the resources necessary for each stage is estimated.
13. What losses? The total expected losses are computed for comparison with the planned resource expenditure.
14. What risk? The residual risk remaining after the planned resource expenditure is estimated.

Clearly, Table 1.1 is not a final representation of the necessary steps for achieving an adequate overall response to blowouts, but it does contain the basic questions and stages that are important for ascertaining an overall management system. The table is designed to show the allocation of resources to the overall risk connected with the blowout of wells. A basic premise is the need to balance resources and risks at each stage of the response system. From this very general approach, alternatives can be considered for the most important stages – blowout prevention, well control, and pollution control. Rescue procedures and personnel safety have been extensively considered elsewhere and so will not be discussed here.

PREVENTING BLOWOUTS

Figure 1.2 shows measures that are involved in preventing a blowout. This figure is modeled on the prevention system designed and used for the North Sea [4]. Since two blowouts have subsequently occurred, it is obvious that these preventive measures are inadequate. Although this book does not emphasize the preventive aspect, it is of interest to discuss its usual extent and some associated problems.

A preventive system must begin with planning of each well, including a careful interpretation of the geological strata to be penetrated. Such interpretations and predictions are used to locate and design the well and draw up the drilling program. The drilling program details the equipment to be used, the casing size and depths, the drilling-mud program (quality and density of mud), and any specialized training necessary for the operators. Operation of the well is based on effective supervision and continuous monitoring of the drilling. Monitoring is done by lowering a device into the well to assess the drill bit as it cuts, as well as by analyzing the cuttings and mud at the surface as they circulate back from the drilling. Well maintenance is especially critical, since both the drill string and the casings, which maintain the shape of the shaft, are removed. At this time the well is unprotected at the surface until the manually activated blowout preventer valve (BOP) is placed on top of the open wellhead. Mud flow and density are of particular importance during this period to maintain the pressure balance of the well. Finally, should the well pressure go out of balance during drilling or maintenance, it is recommended that a valve be available, which can be activated automatically or manually, to shut down the well if the pressure becomes too great to adjust the mud flow quickly.

The key to maintaining the required pressures in the well is effective drilling supervision, because the original drilling program may not be in accord with actual conditions experienced at the well. The drilling supervisor bases his decisions on the monitoring of results from samples received via the drill bit as it cuts through the strata and from the recirculated drilling mud. The flow of fluid from the hole is a continuous indicator of well balance, so that adjustments in mud density or drilling can take place immediately. Needless to say, the physical presence of alert personnel with adequate offshore training and experience are vital for effective drilling supervision. Drill-crew training is also important if sudden abnormal conditions are to be dealt with quickly and correctly.

Organizational and personal factors in the drilling operation are also important. Personal attitudes to safety are paramount as attitudes directly influence behavior in both routine and critical operations. The actions of individuals must be meshed in with those of other individuals and also with complex moving equipment so that questions of organization are of great concern. One feature of North Sea operations is the use of multinational crews, all of whom must be integrated into a safe operation. In addition, these multinational

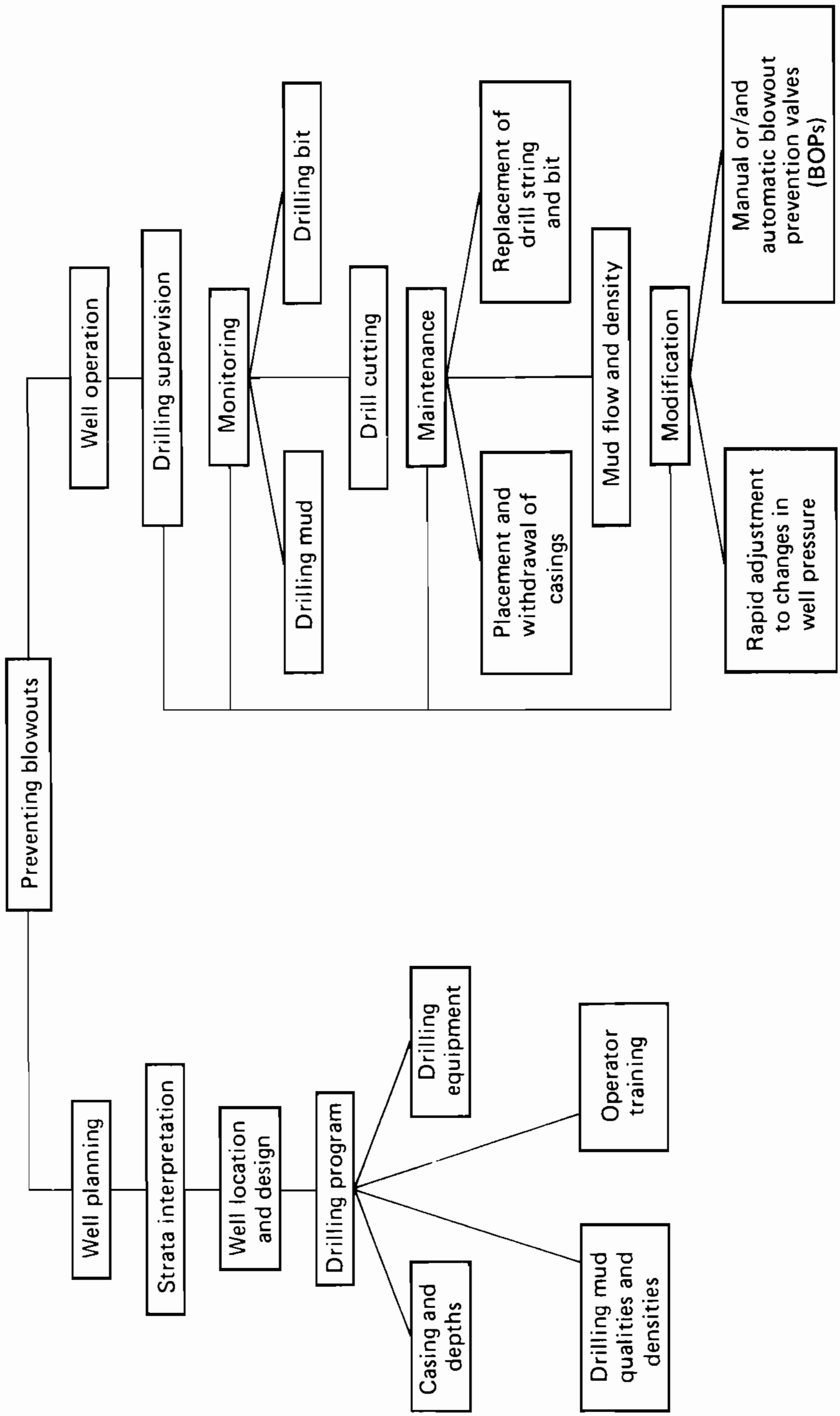

FIGURE 1.2 Prevention system for well blowouts.

crews change shifts frequently and there is a constant interchange of contractors and subcontractors working on various aspects of drilling, each bringing with them different work experiences from different rig designs. This pattern of work instability in a physically confined space, and in the presence of moving equipment, high pressures, flammable hydrocarbons, and often stormy weather conditions make organizational structure and integration crucial safety variables.

In the North Sea the international oil company style of operation comes into conflict with the national style of operation, particularly in the Norwegian sector. International oil companies have evolved a particular style of operation which views the various drilling and support personnel as interchangeable parts, each having a detailed job description and being regulated closely by a supervisor. In the Norwegian sector personnel are viewed in the same way as other shore-based staff: each worker is seen as independent, with a considerable degree of self-regulation. Also the international style of detailed job training emphasizes rigid job demarcation and the separation of drilling from other functions whereas Norwegian safety training suggests integration of these functions. These potentially conflicting operational styles can create difficulties in emergency situations that require a flexible response among different specialists with different backgrounds [5a].

As a backup system to drilling supervision, BOPs are fitted. Two such BOP systems are used in the North Sea: an automatic downhole safety valve located 50 meters under the seabed after the well has been fully cased, and a manual system at the well-head. The automatic BOP is designed to shut down the well immediately a sudden change of pressure occurs. Although these valves were considered failsafe, the Norwegian blowout showed that such a valve failed to function and indeed was itself blown out of the well. The individual manual BOP is placed on top of the wellhead whenever the well is open, such as after the drill string has been pulled during a well workover or maintenance program. The BOP must always be in position, correctly assembled and maintained, and correctly connected to the wellhead. Again, experience with the Norwegian blowout showed that such valves may not work as planned during a well workover [5b]. As a result of this experience, the Norwegians are considering the use of a third BOP between the sea surface and the seabed.

In addition to well planning and operation, the design and use of the offshore platform itself are of the greatest importance. The unfamiliar and hazardous conditions in the North Sea, the depths encountered, and economies of scale have led to the use of enormous platforms that are each capable of drilling over 50 wells. This major innovation has placed a significant burden on the shoulders of both the oil industry and its regulators in regard to design and accident-response.

One technique that is employed in the design of these massive platforms is risk analysis [6], which is a method for estimating the failure probability of a system. Risk analysis was originally developed for assessing military and space-travel programs and was later applied to large technological equipment such as nuclear power plants: its use in the North Sea is the first application by the oil industry. In this case, the technique was designed to obtain an estimate of the risk involved in a platform design. The probability of failure of each component of the platform was estimated by considering the probability and magnitude of factors that would adversely affect that component. For this purpose, not only routine operations were taken into account, but also possible hazards to the components from fire, storms, waves, dropped loads, etc. After modifying the design to mitigate the effects of such hazards, the residual risk is calculated.

The bases for a risk analysis are often fault trees, event trees, and consequence analyses (for a review of these techniques, see ref. 7). Fault-tree analysis is deductive since it begins with a definition of an "undesired event" and proceeds by identifying a set of contributory events. The method provides a diagram, or fault tree that symbolizes the relation between these events. Since this fault tree can be quantified, the frequency of the undesired event can be assessed, and judgments made about the quantitative and/or qualitative importance of contributing events. For example, the causes of a malfunctioning safety valve can be traced via a fault tree; these might include failure to detect a fire, a change in pressure, or lack of maintenance.

The complement of the fault tree is the event tree. Whereas the logic of the fault tree begins with an adverse event and works back to its causes, the logic of the event tree works forward to the consequences of an initiating event. For example, a load dropped onto a platform may damage a wellhead which in turn may generate a blowout. Consequence analysis amasses the expected adverse consequences that would result from a component failure.

Fault trees and event trees not only help the analyst to acquire a good understanding of the system, but also provide a comprehensive documented account of the process. This documentation is useful when reviewing the analysis at a later date. Thus, insights can be gained into the basic design concepts, which gives an integrated picture of the operations of the system. While these methods are helpful for preventing malfunctions and providing a basis for preventive measures, there are many limitations [7, 8] including the following: the trees can mask other pathways to disaster that are unknown, ignored, incorrectly displayed, or discounted; the scope of an external adverse event or simultaneous set of events can extend beyond the depicted trees and lead to disaster; tradeoffs among alternative risks may be masked; and risk estimates assigned to each branch of the tree often vary.

Experts are often unable to determine missing pathways in trees or they assign probability estimates incorrectly. For example, the BOPs, which had been considered "failsafe" by the oil industry, did not stem the blowout at Bravo. One interesting case where different evaluations of risk and cost had to be reconciled was the suggestion by the Norwegian authorities that crews be housed on a separate offshore platform. Thus, a tradeoff had to be made between, say, the risk of helicopter transportation versus the risk of fire and explosion. In the end, crew quarters were placed on the drilling platform but in a carefully chosen location and with protected walls and escape routes.

Platforms are designed for safety as well as operating efficiency. At present, emphasis is placed on enhancing the reliability of shutdown systems by using the best possible design [9]. Problems remain in the overall design process, however, in that maintenance of the platform over its operating life does not seem to have been adequately considered. Nor has well capping been considered in the design of large, concrete, multiwell platforms. In the design of North Sea platforms the effects of corrosion, the difficulties of underwater inspection, and the costs of maintenance, including possible shutdown times, seem to have been grossly underestimated [10]. Detection and measurement of structural defects, including cracks and corrosion, by commercially available equipment proved impossible in one underwater trial [10]. Both steel and concrete platforms are subject to the problem of detecting and repairing structural defects, and maintenance is frequently necessary long before the predicted date. Concrete is now being used to sheath wells, making it nearly impossible to detect which well is out of control during a blowout. Thus, corrosion protection on the platform hinders the blowout response.

The height of the newest concrete platforms is greater than the height to which fire vessels can spray fire-fighting material after a blowout. In addition, the wellheads on these platforms are grouped together and covered to protect them from dropped objects; this can hinder a capping operation. The height of the platform also retards capping because a barge cannot be used as a working base.

Table 1.2 lists some important factors involved in determining the overall risk profile of an offshore blowout. A thorough study of operations on the platform is important before attempting to predict the occurrence of blowouts, their effects, and the necessary response to such situations. Spill analysis can lead to an estimate of where and how in the system blowouts can be expected, and what exacerbating events could affect these probabilities. Slick analysis suggests the kind of oil slick that will ensue, where its effects can be expected, and under what conditions. Damage analysis considers the combined effects of platform operating conditions, spill potential, and slick forecast. Integrating all of these factors provides a risk profile for the platform.

Although it is important to carry out as complete an analysis as possible, it must be recognized that a risk profile can never be considered as complete, i.e., a risk profile is itself subject to risk. The analyst, operator, and regulator must all be aware that it is not possible to build all elements of risk into a profile. At best a risk analysis is only an indicator of risk.

The organization of the prevention task can meet with a conflict of interest depending on which government agency has responsibility for safety. The two basic organizational alternatives are to treat safety separately from operations or to amalgamate the responsibilities in one body. The pressure of meeting national and industrial energy-production objectives meets the pressure of ensuring adequate standards of safety in both organizational forms; however, a separate safety body can bring safety–production tradeoffs into the realm of public scrutiny more readily than a body that has operational responsibilities.

TABLE 1.2 Elements contributing to the risk profile of an offshore blowout.

Operation	*Damage analysis*
Platform design	Fatalities/injuries
Drilling time	Structure damage
Workover time	Capping/relief well possibilities
Training time	Location of source
Equipment availability	Drift of slick
Blowout detection and responses	Migration/spawning times
Rescue capabilities	Weather conditions/season
Spill analysis	Coastal ecology
Where well breaks	Methods of treatment
Other wells affected	Effects of oil
Fire, explosion	*Risk profile*
Reservoir characteristics	Initial events
Slick analysis	Contributing events
Oil type	Blowout event(s)
Spill rate	Adverse events
Quantity expected	Consequences
Winds, currents	Response capabilities and interfacing
Spread, direction, timing	Public reactions

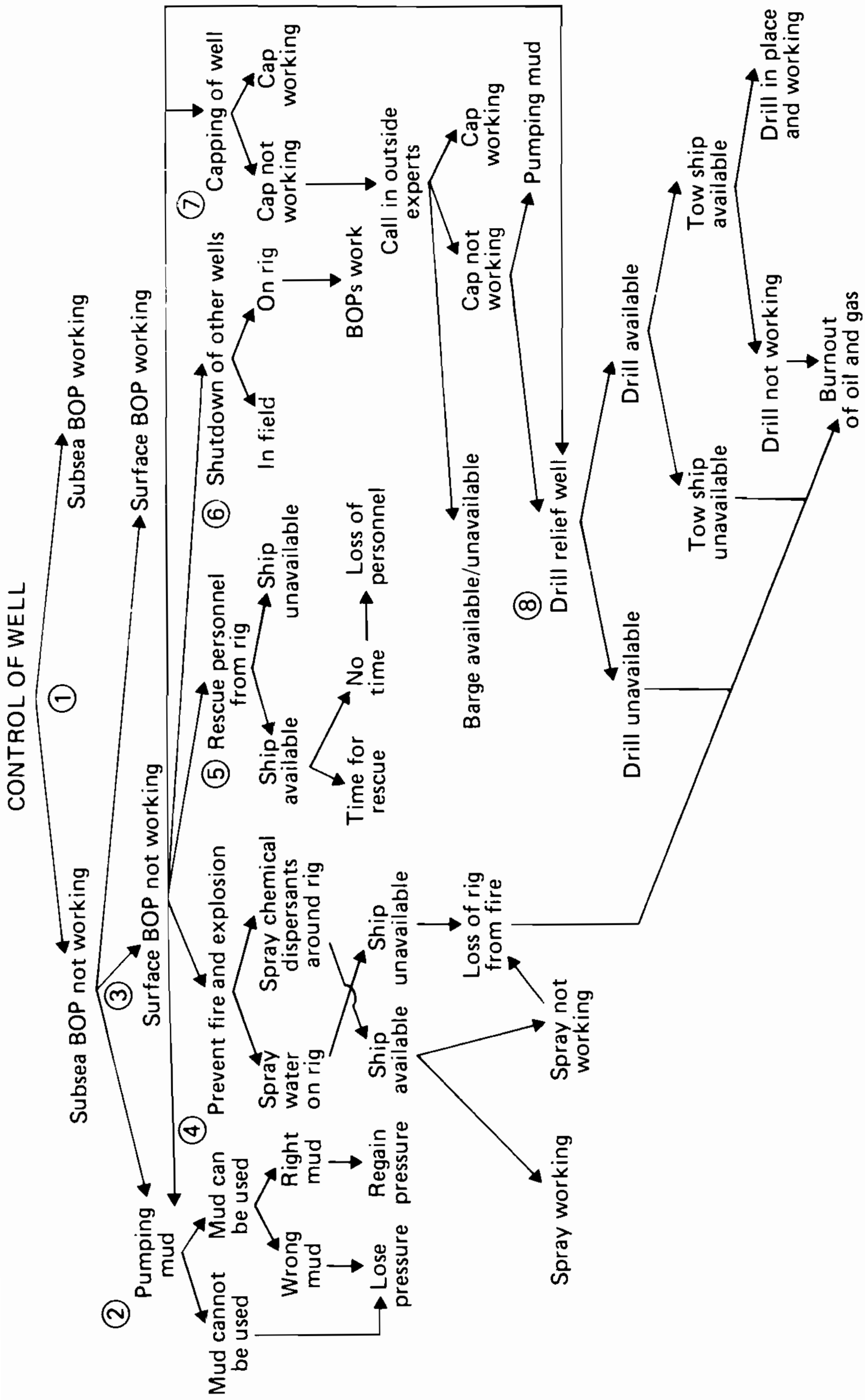

FIGURE 1.3 **Steps in the response to an offshore oil blowout.**

Questions of efficiency and conflicts of interest are at the core of this organizational problem. Norway has moved from a position where safety was the responsibility of a single agency to one where it is split between agencies, while the United Kingdom has changed from having safety as a separate responsibility to a new situation in which the functions of offshore safety and operations are consolidated into one body.

WELL CONTROL

Should a blowout actually occur, the priority is to regain well control. Figure 1.3 outlines the various steps for attempting to do this, i.e., to obtain pressure control. The first line of defense is the BOPs, the automatic subsea BOP, and the manual surface BOP. Should these BOPs not operate, mud pumping must be stepped up; indeed, mud pumping begins as soon as well pressures begin to rise and before it is necessary to shut the manual surface BOP. At the same time, a fire-prevention spray program begins to dampen the rig and allow shutoff of all wells on the rig. Rescue of rig personnel also occurs at this point so that the use of BOPs, pumping of drilling mud, other well shutdowns on the rig, fire prevention, and personnel rescue all occur at approximately the same time.

After the rig has been abandoned because of a blowout, work must commence on a capping operation. The capping effort can be carried out initially by the operator, but usually outside experts are then called in. Either simultaneously with capping, as an alternative to capping, or if capping fails, a relief well is drilled near the uncontrolled well to pump mud into the oil reservoir to regain pressure control. If this drilling effort fails, the well will continue out of control until all of the oil and gas is dissipated.

Figure 1.3 lists the several steps of importance in attempting to regain well control. Steps 1 through 7 occur nearly simultaneously, with platform personnel attempting to gain control of the well before it blows. A fire at the wellhead fuses piping and can cause failure of the subsea BOP. The functioning of the surface BOP depends on the watchfulness of the drilling supervisor and efficiency of the crew in closing off the well properly and on pumping the right density of mud into the well to regain pressure. Normally, only a fire or explosion would prevent an attempt to pump mud or activate the manual BOP. In the Norwegian-sector blowout the BOP could not be activated because it was not in the proper position (see Chapter 2). Complications include fire, explosion, and the necessity to shut down other wells on the platform. Detection of the blowing well can also prove difficult.

A blowing well may be controlled by four methods: (1) bridging – the well collapses or becomes clogged because of materials in the structure; (2) capping – the well is controlled from the surface by mechanical means and muds; (3) relief well – a new well is drilled into the structure to relieve pressure; and (4) emptying – the well completely empties the reservoir. These four methods contain two natural and two man-made possibilities. Figure 1.3 does not include bridging or emptying as alternatives because it is assumed that a blowing well will be brought under control as soon as possible. If natural bridging is not expected, explosives can be used to induce artificial bridging. On the other hand, if the structure is a small gas pocket in a sandstone structure and the well is isolated, it may be decided to let it blow itself out. However, if bridging occurs, it is not known if the well will remain clogged, so that normally a capping or relief-well operation will continue until the extent of bridging is known. At this point, if bridging is judged to be permanent, the relief well can be reclassified as a production well.

If no fire is present at the blowing well, a capping operation is considered. For capping to be undertaken there must be little or no damage to the wellhead as well as an adequate platform from which to assemble equipment and to work on the well. Often a barge or drill ship is used for this work. Fire protection is of major importance and, should a fire exist, it is paramount that it be extinguished before capping can be undertaken.

Capping consists first of closing the valves on the "Christmas tree" atop the wellhead. If this proves impossible, an attempt is made to pump heavy mud or cement into the well. Should such pumping also be impossible, then a new shutdown valve must be installed, such as a "blind" or "shearing" ram forced across the well opening by hydraulic pumps. A newer technique for capping a well is called "crimp and plug"; this crimps the well pipe so that injected steel and rubber balls can cut off the flow at the crimp. Then the crimp is tightened and mud pumped into the well to kill the pressure [11].

Capping is complicated by high reservoir pressures, high blowout rates, large amounts of gas, high temperatures, and complex platforms with poor access and working surfaces. In addition, other hazards can be present, such as stormy weather, an underwater blowout, blowing sand, a gas vapor cloud, an explosion potential, a fire potential, a poisonous gas cloud, and platform damage. Stormy weather inhibits the regaining of well control, escape from the platform, and provision of a working platform (or barge) adjacent to the blowing platform. An underwater blowout requires divers to crimp the well pipe. A subsea blowout that leads to oil and gas escaping outside the well itself can result in cratering and possible collapse of the geological structure, including the platform if it is anchored to the seabed. Gas clouds can create explosions and poisonous gas clouds (H_2S) can kill. Fire can cause explosions as well as generate additional blowouts and render escape and capping impossible. Sand from the blowing well falling on the deck of the platform can overload it, causing collapse.

Relief wells are the last major possibility for controlling the well. While this alternative is slower, it is thought to be the most effective way to bring a blowing well under control. One problem offshore is the scarcity of platforms available to be towed to the site and the relatively long distances to be towed, including the possibility of stormy conditions delaying the estimated arrival time. However, even a relief well can suffer a blowout because of stress, lack of knowledge of the structure, or small gas pockets encountered en route, hence flexibility in the drilling procedures is essential. Indeed, one source [12] suggests that two relief wells should be drilled simultaneously: one into the casing "shoe" of the last casing of the blowing well and the other into the reservoir at the foot of the blowing well.

Should a major oil blowout from a large reservoir be involved, several relief wells may have to be drilled, each with a large capacity for pumping mud, because of inaccuracies in drilling and measurement, which can lead to deviations as great as 40–60 meters. This problem occurred with the Mexican Ixtoc blowout where the first few relief wells missed their target zone. Possibilities of error in the North Sea, with the greater depths, darkness, and inclement weather, would appear more likely than those in the shallower, lighter, and calmer Gulf of Mexico. However, well logging or recording is far more frequent and strict in the North Sea than in the Gulf of Mexico.

In general, it takes 100 days for one relief well to be drilled to an average reservoir depth of 2,500 meters [12]. A pumping barge is also needed with a large number of

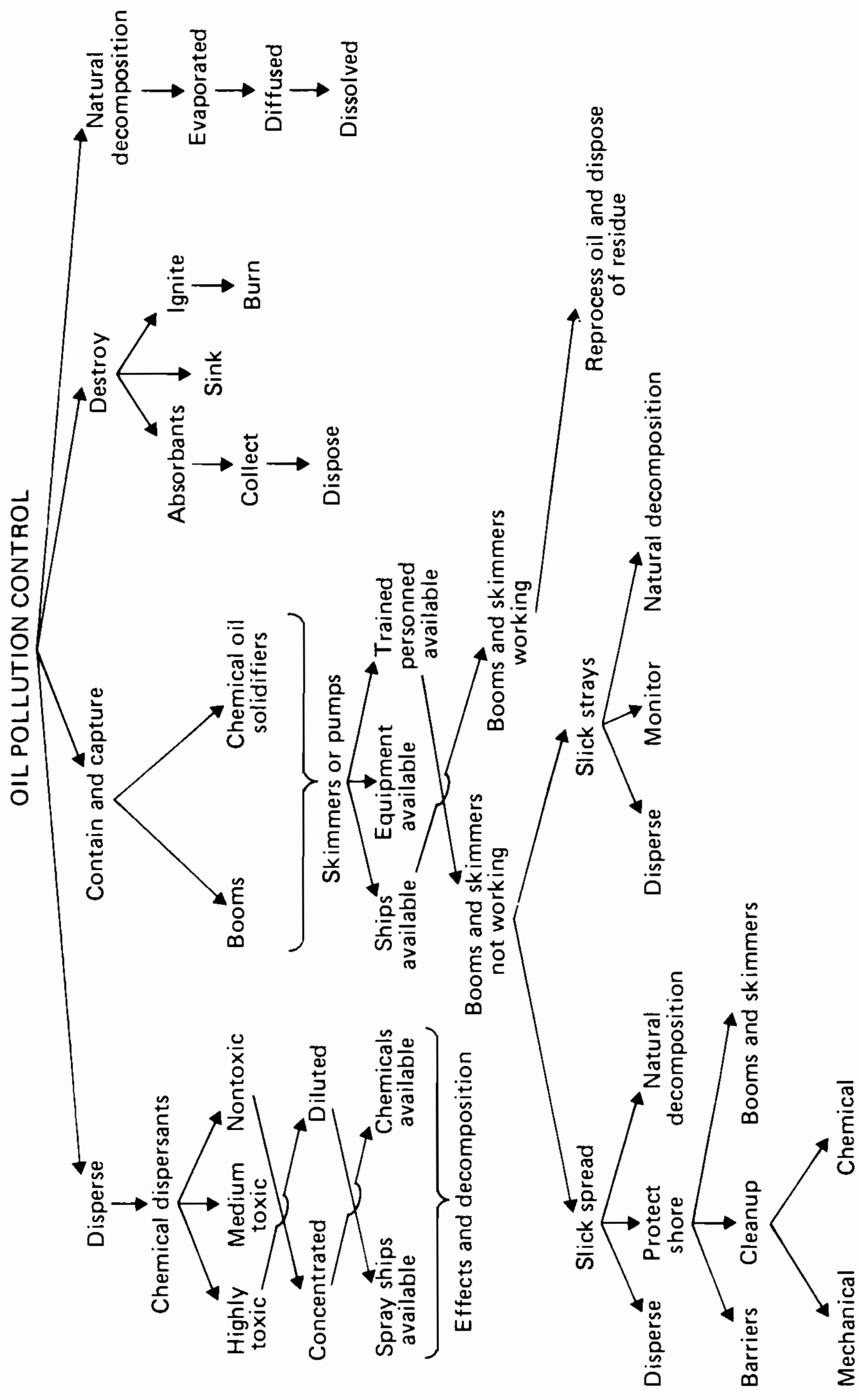

FIGURE 1.4 Alternatives available for offshore oil pollution control.

pumps for each relief well. The time needed to find such a barge or to convert another vessel for pumping by installing the requisite pumps and control equipment must always be kept in mind.

Relief drilling can be complicated by the water depths involved, as well as by stormy conditions. Two types of platforms or rigs can be used and qualitative differences exist between them. The jackup rig can be jacked up adjacent to the uncontrolled well, thereby ensuring that it will relieve the blowout pressure. Its disadvantages include the requirements for shallow depths, good weather, and a stable seabed for placement. The semisubmersible rig overcomes these disadvantages but it has a disadvantage of its own – the long distance from the blowing well where it is placed on site, which is such that the ability to relieve reservoir pressure is more uncertain. Mooring the semisubmersible rig can also be a problem in stormy seas. Finally, stormy weather can present problems while these rigs are being towed to their drilling sites.

POLLUTION CONTROL

While the well-control effort is under way, work must begin on combating the oil that is spewing from the well during a blowout. The basic principle governing antipollution work is to capture or dissipate as much oil as possible near its source. Figure 1.4 shows the alternatives available: the first three, dispersing, containing, or destroying the oil, require the intervention of the decision-maker, whereas the fourth, natural decomposition, occurs continually. Destroying the oil slick is not possible in all cases because of the difficulties inherent to this measure and its dependence on weather, location, concentration of slick, and availability of materials. While burning is an acceptable method for small platforms in the USA, the UK and Norway do not consider this option viable because of the size and productivity of their platforms, the possibility of losing such a huge offshore platform, and the possibility of additional blowouts from a multiwell rig.

The two basic pollution-control alternatives for major oil spills in the North Sea are dispersal and containment. These alternatives work on completely different principles, so that one method cannot be efficiently and effectively used if the other has been tried but proved ineffective. Although dispersants can be applied at any time, they are most effective when the oil is fresh; therefore, a decision to attempt containment and capture of an oil slick also rules out the most effective application of chemical dispersants. According to Norwegian officials, the main disadvantage associated with dispersants is their possible impact on the marine environment. Factors to be considered are the time of year, the state of fish migration, eggs, and larvae, the weather forecast, and the direction of currents. The wide use of dispersants in the UK sector is based on the advantages of rapid deployment, reasonable effectiveness under all navigable weather conditions, the relatively low capital cost, and the ease of use by even untrained operators.

Tests carried out in the UK to contain and capture oil at sea found the equipment to be ineffective under most conditions to be expected in UK waters. Mechanical operations are difficult to mount, and ineffective under moderately bad weather conditions; they have high capital costs and require trained operators. Even though these disadvantages exist, mechanical systems continue to be of interest because of their advantages [13] of "removal of pollution potential, no ecological consequences, claimed high and sustained recovery rates and relatively low operating costs." Although no ecological effects can be directly attributed to the use of mechanical equipment, should such equipment fail to retrieve the oil, pollution of coasts and other sensitive habitats and danger to marine species can result.

Spill size and location, as well as wind and current direction, are the crucial factors in deciding which of the two basic alternatives to employ. These factors are important, even if the general principle of using only one of the alternatives has been established.

Shore protection is important because the coastal zone is the area of greatest potential ecological damage. Also, the cost of shore cleanup after the oil reaches the coastline is very high because of the amount of labor required. Therefore, the emphasis must be on dealing with the oil slick before it reaches coastal waters. The key ecological tradeoff is oil on the shore versus chemicals in the sea.

Sequencing of these alternatives is necessary. Directly around the source of the oil blowout chemical dispersal is essential to help remove the fire hazard to the offshore platform. At sea either dispersants or containment can be used, while barriers, containment, and cleanup are required inshore.

Deploying chemicals is not complicated, but measures are necessary to ensure the correct use of the designated chemical agent and proportion of mixing water, and the correct concentration of spray per unit area. If used correctly, the chemicals do disperse the oil from the sea surface down into the water column. Therefore, dispersant activity speeds dilution and supplements the natural decomposition process. In general, the rougher the sea, the faster will the oil slick be dissipated naturally. Thus, a balance exists since, if the weather is too rough for spray vessels to put to sea, then natural decomposition occurs more quickly.

Controversy over the use of chemical dispersants results from the misuse of such sprays on the oil spilled from the tanker *Torrey Canyon* in 1967. Since that time dispersants have been improved and their toxic effects reduced to acceptable levels. Today dispersants are an important tool for combating oil spills, whether from tankers or blowouts [14]. However, scientific agreement has not been reached about the short- and long-term effects of low-toxicity dispersants [15].

Deploying mechanical means to contain and collect the oil slick is difficult, even if the equipment works as specified and tested. As noted in the next chapter, which describes experiences with the mechanical pickup equipment at Bravo, the specifications provided by manufacturers do not match actual performance. Assuming good performance, however, a major problem is in deploying so many vessels, booms, and skimmers. For example, four boats could be required for every, say, 500 meters of boom: one at each end of the boom, one to skim and collect the oil, and one to carry it away. If 10,000 meters of booms are needed, the many vessels become exceedingly difficult to coordinate. Also there are problems of matching designs in booms and skimmers and finding trained crews and vessels capable of remaining in place in rough seas. Again, if the sea is too rough for mechanical pickup to be employed, natural decomposition is enhanced as the oil slick is broken up and mixed with seawater.

To capitalize on the ecological advantages of mechanical methods, research is continuing on more effective and efficient methods of pickup. Interest is now concentrated on the possibility of using a single converted oil tanker as the means for containing, collecting, and storing oil [16].

Because of the need to deploy limited mechanical means to areas of greatest pending impact, interest has also focused on predicting the drift, spread, and weathering of oil slicks. Several models have been developed and tested, and one was used at the Bravo blowout [17].

ADVERSE EVENTS

External events are important in determining the appropriate responses for well and pollution control. Table 1.3 lists the major events that are possible in North Sea blowouts. Each of the adverse events listed is external to the system of planned responses to a blowout; however, these events are crucial in determining the success of the efforts made to control the well and its pollution. Should a blowout occur in winter darkness under prolonged stormy conditions, little can be done to control and cleanup the flow of oil, even if the amounts of oil exceed 10,000–15,000 tons per day for weeks. Also under such conditions, towing and placing a relief rig is impossible, as is bringing a vessel or barge to the platform for use in a capping and pumping operation. In addition, personnel rescue is hampered. Finally, vessels assigned to oil cleanup are unable to operate in the area. Therefore, weather forecasts are important to offshore drilling operations [18].

Fire-fighting is a major task associated with blowouts, but North Sea platforms are so large and complex that this operation is difficult. For instance, a problem already mentioned is that existing fire-fighting vessels cannot be used against fires on the newest offshore platforms because the height of these platforms exceeds that of the water spray.

Collapse of a jackup rig following a shift in the seabed is possible [19]. Although semisubmersible platforms are being increasingly used for drilling, they are still anchored to the seabed. Of course, collision is a threat both during the towing operation and while drilling or production is under way. Pilot error and faulty radar or guidance gear have been contributing factors to the collision of some oil tankers in the North Sea and the English Channel. For example, during a twelve-month period 26 registered violations by ships occurred within the 500-meter safety zone established around the Norwegian Ekofisk complex in the North Sea. One ship came within four meters of one of the legs of a producing platform before being stopped, while the abandoned UK cargo ship *Hero* nearly drifted into a pump platform at Ekofisk.

TABLE 1.3 Possible events influencing the responses to an offshore oil blowout.

Well control	*Pollution control*
Blowouts from other wells on rig	Location of blowing well near coast
Fire and explosion damage	Another blowout elsewhere in North Sea
Loss of rig in explosion	Prolonged stormy weather
Loss of rig from collapse or collision	Strong inshore winds and currents
Casing ruptured below sea level	Winter temperatures increasing the brittleness of booms
Blowout outside casing causing cratering	Winter darkness
Subsea well blow away from rig	Migration times and routes
Rig blown off location	Spawning times and sites
Prolonged stormy weather	
Winter darkness	
Towing and placement of relief rig	

Simultaneous blowouts and oil spills are also a possibility: a blowout almost occurred elsewhere in the Norwegian sector during the Bravo accident. Given the multiwell platforms being used, this possibility is serious. In addition, an oil spill occurred in Danish waters after Denmark had committed most of its cleanup equipment for use at the Norwegian Bravo platform.

For a summary of 33 blowouts over the years 1970–1977 the reader is referred to ref. 12. This report also describes key operations and external events that comprise blowout risk and response.

RECOVERY AND LESSONS

Recovery from a major blowout varies with the blowout concerned, but, in general, recovery of production itself is not difficult. Production from other wells at Bravo commenced the day the blowout was controlled, and no pollution measures were necessary. In Denmark the damaged exploratory well Vagn-1 was shut down and another well was drilled nearby. Again pollution was not an issue. If a rig is lost or severely damaged, recovery of the drilling and/or production capacity takes longer. Pollution cleanup of oil-soaked coastal areas, of course, adds to the recovery time.

Questions of liability are normally raised during the recovery stage. Because no completely satisfactory method of oil removal exists and because each North Sea country has different interests, liability for blowouts remains at issue [20]. Three basic difficulties are proof of liability, protection of interests, and adequacy of compensation [20]. The issue of proof of liability revolves around the problem [20] of "what standard of care should be required of a person engaged in socially desirable activities which, even though carried out with the greatest care, because of their nature may still result in injury to someone?" Considerations include who is most able to bear the loss, who can most easily pass the cost on to others, and who owns and is responsible for the activity.

The issue of protection of interests concerns proof of loss of property. In other words, a property loss directly linked to the activity in question, such as the loss of a fishing net on an underwater obstruction put in place by an oil company must have been sustained. One interesting problem posed by this issue is that oil companies are required to place subsea well completions and abandoned wells below the surface of the seabed to avoid contact with fishermen's nets. However, the response to a near-blowout from such a sunken well in the Danish sector was inhibited by the position of the well. Had the well been just above the surface and marked on fishing maps, both blowout response and fishermen would have benefited. In the UK sector, wellheads stick out from the seabed, but they are marked by buoys and supplemented by warnings to fishermen.

The last basic liability issue is concerned with the value of compensation. The North Sea operators have created an insurance scheme, known as the Offshore Pollution Liability Agreement, which provides compensation for those harmed by operator-induced oil pollution. This agreement was an interim measure until the North Sea states secured agreement on a convention. At present these states have an agreement limiting liability from the effects of oil operations to US $25 million, with a gradual increase to US $50 million. If oil pollution from a blowout goes beyond national waters, a claimant has the option of seeking relief under either international or national law, whichever gives the better protection. Less proof of liability is required under international law.

TABLE 1.4 Summary of UK and Norwegian responses to blowouts, 1978.

Item	UK	Norway
Prevention	Department of Energy appointed private certifying authorities (e.g., Lloyds) to which companies submitted their designs for evaluation; issued guidelines which form basis for certifying authorities' standards; other government bodies also evaluated and approved parts of the design Emphasis on operator responsibility with contingency plans required	Petroleum Directorate evaluated and approved each company design even though it used evaluations by certifying authorities; other government bodies also evaluated and approved applicable parts of the design Required formal risk analysis of design concepts submitted by companies Emphasis was on operator responsibility with contingency plans required
Rescue	Company responsibility with government sponsored rescue centers on standby Human safety transferred to separate body	Company responsibility with government sponsored rescue centers on standby Human safety transferred to separate body
Well control	Availability of fire vessel to be decided Emphasis on a platform ship as a capping base but relief well used if necessary	Availability of fire vessel Emphasis on simultaneous capping and relief well drilling Capping equipment required on platform
Pollution control	Emphasis on chemical dispersants but must be used with government permission Rule was toxicity of chemical + oil $\leqslant$ toxicity of oil without chemical Mechanical only considered if an effective means found	Emphasis on mechanical pickup with requirement for each company to have such for picking up 8,000 tons of oil per day in 2.5-m waves Chemicals only used to protect the platform from fire unless otherwise decided by government
Organization	Permanent advisory group headed by Department of Trade representative with an environmental advisory panel; reports to Ministerial committee	Permanent Action Command headed by environmental representative who reported to Minister of Environment; use of day-to-day regulators and scientific institutes
Feedback	Following the Bravo blowout an ad hoc committee recommended shifting occupational safety from the Health and Safety Executive to the Department of Energy, thus splitting offshore safety from the national safety body; shut-down systems to be certified; systematic approach to design and construction encouraged.	Following the Bravo blowout, the responsibility for all offshore safety was consolidated under the national safety body, the Ministry of Labor, although day-to-day offshore safety is still under the Petroleum Directorate as the inspection and approval body Drilling north of latitude 62° N was postponed until Parliament is satisfied that adequate safety measures are available

The lessons learned from a blowout are as important as arresting the blowout and containing pollution. Adequate feedback channels must be created and maintained to ensure that the resultant problems are recognized, evaluated, and incorporated into existing operations. Some methods for ensuring feedback are given below.

1. Creating a permanent coordinating committee for assessing emergency responses, including offshore blowouts, and the actions of the emergency command group.
2. Requiring evaluations of the actions of all participants in a blowout response, both from the individuals themselves and from independent experts.
3. Investigating the causes of a blowout by means of an independent quasilegal review board.
4. Preparing state-of-the-art reviews and comparisons of actual operations before, during, and after a blowout response.
5. Including political, news-media, environmental, scientific, and fishing interests in assessments of blowout response.
6. Requiring that oil companies incorporate the experience gained into their existing operations.
7. Providing adequate government and industry infrastructure, training schools, testing sites, research funds, etc.
8. Generating realistic sanctions, together with frequent inspections, requiring the immediate reporting by operators of malfunctions, and enforcing shutdowns for violations.

The overall objective of these requirements is to reinforce the concept of operator responsibility in blowout prevention. Such channels as these act as means for feedback from past blowouts to current activities and help to ensure the basis of a safer management system. A framework for such a feedback mechanism can be found in an earlier study [21]. A danger in attempting to apply lessons learned (besides correctly ascertaining the lessons) is that overreaction may result. Too onerous a set of requirements may be placed on the operator or be beyond the capacity of the regulator to enforce. In addition, too many resources may be channeled into prevention at the cost of the response system, or the latter may be emphasized at the expense of prevention or the actual damages sustained. For example, it has yet to be demonstrated that damages from oil pollution on the high seas can justify the resources consumed in combating such pollution there.

UK AND NORWEGIAN RESPONSES TO BLOWOUTS

Table 1.4 summarizes the current posture of Norway and the UK with regard to blowouts. No attempt is made to compare these postures, as each country decides its requirements according to its own position and assessment. A major trend, however, is the growing awareness that a mutually agreed response is necessary to meet the blowout and tanker-spill problems. United Kingdom and Norwegian interests have now met to clarify issues under a bilateral agreement [22].

Both the UK and Norway hold to the principle that the oil industry itself is liable for the costs of dealing with an incident, including overhead costs of cleanup and depreciation on equipment [23]. The major difference is that the UK has a ceiling on liability, whereas Norway claims unlimited liability. Both countries also hold that the oil industry is responsible for cleaning up oil spills offshore and that responsibility shifts to government only when public interests are at risk through the inability of the operator to cope, inadequate methods are used, or where oil escapes threaten the coast [23].

As time passes a combined but similar response to well and pollution control, which maximizes flexibility and effectiveness, should emerge, even though the styles of operation might differ as Norway has a more centralized governmental approach to blowouts than the UK. The two countries view the major threat in a significantly different way: the UK is most concerned about major oil spills from tankers going round its coasts to the Netherlands and West Germany, while Norway, which has a smaller offshore drilling program than the UK and fewer tankers passing its coasts, is concerned about the extension of drilling in its northern waters where major fishing areas exist.

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2 THE OIL AND GAS BLOWOUT AT BRAVO PLATFORM, EKOFISK FIELD, NORWEGIAN SECTOR*

David W. Fischer

On April 22, 1977, the offshore oil well B-14 went out of control in the Norwegian sector of the North Sea. From this time until control was regained on April 30, a maximum of 22,500 tons of oil escaped from the well [1]. Potential revenue from this oil was lost for both the oil company that owned the well and the Norwegian government who owned the subsea shelf; associated products and services also suffered loss, the marine environment was damaged, and the costs of meeting the emergency itself and compensation claims of injured parties had to be borne.

This chapter does not discuss the cause of the blowout, how it could have been prevented, or its impacts. Rather it deals with the management of the crisis after the blowout occurred. While analysts have directed attention to risk assessments of possible blowouts [2], they have devoted less effort to the management of such blowouts once they occur. The strategies employed in an emergency can often reveal the priorities of the core actors by their specific responses to specific situations. Indeed, not only are the priorities revealed, but the selection of alternative courses of action can reveal the way the decision process operated. Thus, this chapter outlines the roles of the actors involved, the alternatives seen as feasible, and the decisions actually taken. Where possible, an evaluation of these decisions is made.

THE ACCIDENT AT THE BRAVO PLATFORM

The blowout at the Bravo offshore well occurred while maintenance work was being undertaken on a production well on a platform housing fourteen other wells. While the automatic BOPs worked on these other wells, the well under maintenance went out of control. The specific causes of this blowout were investigated by an independent commission set up by the Norwegian government; their report was submitted on October 10, 1977 [3]. Any combination of causes, including poor prediction of subsurface conditions, poor well design, poor crew training, and ineffective supervision by company and government

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personnel, could have been involved [4]. However, at the Bravo site the underlying cause of the blowout was found to be that the organizational and administrative systems were inadequate [5].

Red Adair, the famed tamer of oil wells, is reported to have said, while he was in Norway after visiting the well at Bravo, that he has tended more blowouts caused during the repair and maintenance of production wells than during the drilling of exploration wells. His statement was corroborated by the Bravo Commission Report [5]: "A well workover is a major task that is performed comparatively rarely. Experience shows that the blowout hazard is greater for such work than for any other work performed on the field in the production phase." Such statements conflict with the generally held Norwegian view that exploration wells have the highest blowout potential [6].

The blowout at Bravo consisted of a maximum of 2,830 tons of oil and 1,410 tons of gas ejected every 24 hours for almost eight days [7]. No completely accurate measure of these oil and gas losses is available. Foreign matter in the formation itself or in the production pipe might have reduced the amount of oil and gas. Press reports at the time of the incident reported figures varying from 4,000 to 7,000 tons of oil per day, which exceeded the theoretical maximum quoted by the company; however, no bases were given for such figures.

The mixture escaping, of light consistency, was forced through the wellhead at near-boiling temperature and under extraordinarily high pressure. The mixture shot above the platform in the form of spray, and a portion of the oil evaporated before it contacted the water surface. The gas, of course, was nearly entirely dissipated. As the oil sprayed out of the wellhead it was mixed with water sprayed from a fire boat, to prevent the hot oil from starting a fire or causing an explosion that could destroy the platform.

A brown oil slick formed on the waters surrounding the Bravo platform, 1–2 mm thick. The mixing action of winds and waves, as well as water spray from the fire vessel, caused emulsifying conditions to occur, and both the color and composition of the slick changed. The Action Group assumed that half the blownout oil evaporated into the atmosphere, while natural degradation of the remaining oil emulsions caused the slick to disintegrate. The intermittent slick covered an area of approximately 4,000 square kilometers with varying degrees of thickness and contamination of Norwegian waters, although only a small portion reached the Danish sector. The slick did not move toward the coast as initially feared, but remained downwind in the general vicinity of the blowout source through the combined effects of winds and currents. The degree of movement of invisible dissolved oil beyond this area is unknown. The rate of spread of the main slick was less than one kilometer per hour. Observations from daily air flights showed that the slick was almost stationary and would eventually completely disintegrate by natural weathering. Only a few patches were expected to reach the Norwegian coast, the area of greatest potential damage.

The blowout at Bravo was the first major blowout in the North Sea during nearly a decade of drilling offshore. However, recent reports on blowout risk show that such occurrences must be expected in future. A study in the UK by the Department of the Environment notes that data available for the years 1964–1971 suggest that one blowout will occur for every 455 wells drilled in the North Sea, but less than one-third of these blowouts will cause an oil outflow greater than 350 tons [8]. The study pointed out, however, that four minor gas blowouts had already occurred during operation of just over 600 wells in the UK sector, which suggests that the predicted rate is too optimistic. Another study for the UNEP Conference with the Petroleum Industry [9] noted that "accepting a risk per well of 0.0333% (the same risk per well as in the Gulf of Mexico), there is a 50% chance for a major incident after having drilled around 70 platforms." Finally, a Norwegian report [10] notes an average of one oil–gas blowout per 500 offshore wells drilled and comments that, with nearly 1,000 wells drilled in the North Sea, no blowouts have occurred. In fact, the report goes on to imply that blowouts are not foreseen in that "There has been no instance of a blowout in connection with the modern safety controls that are mandatory on the Norwegian shelf."

Not only was the Bravo incident the first major oil blowout in the North Sea, but it was also the first major oil loss in the Norwegian sector. Previous incidents had occurred but were minor. Therefore, little experience had evolved in Norway for responding to emergencies connected with large offshore oil spills. This lack of experience is not to say, however, that Norway was not expecting such emergencies. It simply had not dealt with the actual problems surrounding these offshore incidents.

PRINCIPLES ESTABLISHED BEFORE BRAVO

The government of Norway had established certain principles for dealing with emergencies connected with offshore oil development in the North Sea before the Bravo incident [11]. They can be summarized under four headings:

1. *Principles for the operator.*
   (a) The operator has the responsibility of meeting every situation that might occur.
   (b) The most advanced technology must be available at all times to meet these situations.
   (c) The operator carries unlimited liability for all damages and costs resulting from these situations.
   (d) The operator must have operational plans to meet all possible situations should they arise.
2. *Principles for the regulator.*
   (a) The regulator must give prior approval to operator plans and work procedures through expert agencies coordinated by the Oil Directorate of the Ministry of Industry and Crafts.
   (b) Government to assume responsibility when the operator is deemed unable to handle the situation or the risk of great damage is present.
   (c) Regional emergency response centers to be created along the coast; costs to municipalities in building up facilities to respond to emergencies, as a supplement to operator efforts, to be subsidized.
3. *Principles for well control.*
   (a) Prime emphasis to be on saving human life, e.g., ensuring the safety of platform workers.
   (b) Stopping the uncontrolled flow of oil at the wellhead to be the main objective in combating a blowout.

4. *Principles for pollution control.*
   (a) Operator to contain and capture the oil slick as near as possible to the source of flow, i.e., to clear the oil in the open sea.
   (b) Emphasis to be on mechanical means for stopping oil pollution rather than chemical dispersants.
   (c) Government to participate in research and development on such mechanical means.
   (d) National government to be responsible for protecting the coastline on a cost-recovery basis from the operator.

The Bravo incident provided the first real test of the practicality of these principles. While many of them seem obvious, some carry implications that a priori appear to affect the adequacy of response by both operator and regulator.

The requirement that the operator assumes initial responsibility to meet every situation that might occur with the most advanced technological apparatus available is, in reality, constrained by economics. The operator generates his own response system for meeting this principle, governed in part by his financial position. Offshore operators therefore rely primarily on prevention rather than on oil cleanup technology [12]. To minimize the financial costs associated with oil loss is an objective that ranks in importance with the removal of escaped oil from the sea. Both Statoil in Norway and British Petroleum in the UK are involved in research on oil-spill cleanup technology.

A number of years ago the Norwegian government created and approved a coastal response program and funded it at an adequate level for completion in the spring of 1978, a year after the Bravo blowout occurred. The government also created a regulation in the summer of 1976 that required the companies to develop mechanical pollution-control equipment capable of handling a minimum of 8,000 tons of oil per day. Even though the companies argued against this requirement on the basis of its impracticality, once the regulation was approved the companies began the appropriate research and development programs. This Norwegian posture has been instrumental to the development of new pollution-control equipment for use in their sector of the North Sea, even though such equipment was not ready for use at Bravo.

The principle of unlimited liability also carries with it an economic constraint, since there must be some economic limit to operator liability. Operators insure against blowouts by spreading the risk over several insurance companies who in turn spread their own risk over still other insurance companies. Insurance companies have a risk limit of liability based on their assessments of the risk involved and the governing laws. An agreement in 1976 limited liability for damages from each incident to US $25 million. Although Norway recognizes this insurance limit, it does not recognize a limit on operator liability. At present operators accept this limit, but nine European governments have now updated this agreement by first raising the limit to US $35 million and then five years later to US $45 million [13].

Thus, in practice compensation for damage and cost recovery for the necessary governmental cleanup operations are limited. Both government and the operator have a vested interest in maintaining a flow of oil to obtain royalties, sales, and tax revenues. Should recovery costs and uninsured damages be seen as too costly by the operator, the economic incentive for remaining in a high-cost, high-risk oil field will be reduced. In addition, a government would not readily cancel production permits since it has a financial commitment to oil in the form of infrastructure and outstanding loans, so again operator liability is, in practice, limited. Further hypothetical limits to liability can be imposed by the multinational oil firms changing the organization and financial base of their Norwegian subsidiaries. Should a subsidiary become a separate company with a separate budget, this budget and the company's assets form an absolute limit.

Thus, the government cannot assume there is no ceiling to the liability of operators in its oilfields. In another sense, the final liability for damages from a blowout rests with the owner of the seabed, in this case, the Norwegian government. Other countries sustaining damages from a blowout in the Norwegian sector of the North Sea may have the right to seek compensation from the Norwegian government itself or one of its national organizations.

The principle of maintaining the most advanced technological equipment available is subject to economic constraints as well. At any time the operator can choose whether to install existing equipment or to wait for a technological advance. However, the principle gives no guidance to the operator on how to make this decision, although a penalty seemingly accrues if a technique is chosen wrongly or too soon. The only basic guidance available is from the manufacturers, who are prone to exaggerate the performance characteristics of their own designs. For example, in the Bravo incident the skimmers used proved less effective than their claimed capacities, which were determined under ideal conditions that rarely exist in practice [13]. An operator has also to decide whether to undertake his own research program on cleanup or to invest in a commercially available system for this purpose. Once an operator has invested in a commercial system, he has no incentive to continue research that might render his investment obsolete before its payout period.

The principle of not issuing an exploration and drilling permit to the operator until he has formulated an approved plan for coping with emergencies needs discussion. Company emergency plans were approved in 1977 by the Oil Directorate of the then Ministry of Industry and Crafts [14]. This approval was a condition for granting the exploration and drilling license, the company emergency plan being part of the requirements for obtaining the license. Although the Oil Directorate retains approval authority, it may coordinate various aspects of the emergency plan with other government ministries and agencies as appropriate. The company emergency plan must contain [14]: an organizational plan defining the chain of command and areas of responsibility for possible emergencies; an equipment plan for meeting particular emergencies, including details of the nature and type of equipment, capacity, location, means of transport available, correct use of equipment, place of use, etc.; an action plan for the initial alarm and communications systems, notification of authorities, duties, when and how equipment is to be used, rules for reducing danger, and for when action is to be terminated; and a training plan for platform personnel with appropriate drill procedures.

The overall operator plan submitted to meet these requirements is then split up and coordinated: the pollution contingency plan with the Pollution Control Agency, the well-control plan with the Oil Directorate, the equipment safety and rescue plan with the Maritime Directorate, the personnel rescue plan with the Ministry of Justice (police), the communication plan with the Telecommunication Administration, and so on. If any one of these agencies finds the emergency plan of the operator to be inadequate from their point of view, the entire plan is rejected by the Oil Directorate. Overall well-program approval is coordinated by the Oil Directorate, while approval of the platform itself is coordinated by the Maritime Directorate. Neither of these aspects can be considered before the coordinated approval of the total package.

While the principle of an a priori emergency plan centered on government coordination and approval is important, the setting appears to limit its usefulness. Since the program it tied to the issue of a drilling permit, considerable pressure can be exerted by both operator and government to speed up the process for economic reasons. Hence although the operator cannot theoretically obtain a license without an approved emergency plan, in practice financial pressures might win approval for a less-than-optimum emergency strategy. Thus, a tendency can develop where predetermined investment schedules overshadow items of seemingly lesser immediacy, such as an emergency plan for blowouts (particularly if none has yet occurred, as was the case in the Norwegian sector).

This approval problem is still more acute when there is a lack of an effective means for coping with a blowout and cleaning up oil pollution from it. As the Norwegian government noted [14] before the Bravo incident:

- "The operators have little equipment with which to meet a major blowout. Under the existing rules the operators are required to have such equipment, but the authorities have not yet imposed specific requirements . . .".
- "However it is clear that no mechanical means are available at present which would be effective under the conditions of wind and sea prevailing in the areas under consideration. Therefore requirements relating to dispersants must also be imposed."
- If a blowout should occur there would not be enough chemicals in the North Sea area for effective oil spill treatment."

In view of these statements it was obvious to both operators and government that the emergency plan was in reality a good intention rather than a practical system for controlling and cleaning up blowouts. Thus, it is not surprising that the emergency plans of offshore operators were inadequate and that this inadequacy was well known to the government authorities. Indeed, it is possible that, since such plans were not capable of being adequately carried out, they were not given strong credence in the drilling-permit or well-program approval process. However, as noted earlier, the Norwegian government did approve a set of specific requirements in the summer of 1976 for equipment, and gave the operators one year to meet the requirements.

The principle of relying on mechanical means for responding to oil pollution on the sea instead of cheaper, proven chemical dispersants was not well received by the oil companies because of the greater possibility of damage liability, the greater expense involved, the lack of evidence for the effectiveness of such mechanical systems, and the lack of definition of "best available." In addition, the UK preferred to use chemicals in its producing sector of the North Sea. Nevertheless, the Norwegians still proposed to rely on mechanical booms and skimmers to contain and capture an oil slick, even though these measures were known to be inadequate in the open sea. Because of genuine operator skepticism, little company research was done on mechanical methods of cleanup, although British Petroleum in the UK had developed a skimmer for use on the high seas. Thus, the Norwegian government was almost alone in preferring mechanical methods, which meant that it was committed to demonstrate their effectiveness, even though in theory the operators had to maintain the most advanced systems available for cleanup.

Government research was not carried out to any significant extent, although some funds were allocated to private manufacturers for such research. No training program for boom and skimmer operators existed as it did in the UK, even though the UK did not rely primarily on these methods. Only limited funds were allocated to municipalities for purchasing mechanical equipment to protect their shorelines. At the time of the Bravo incident, however, the Norwegian government and the oil companies had agreed on the design of such equipment and orders had been placed by both government and the operators.

The underlying principle for responding to a possible oil blowout for both prevention and control can be conveniently summarized: the Norwegian regulators rely on the self-interest of the operator to handle the problem, i.e., they base much of their regulatory activities on the operator's own supervision of his oil-exploration and production activities [15]. Such a system of supervision requires a good and continuing knowledge of the operator's supervisory capability and his plans for responses to expected and unexpected events.

The discussion of these principles is designed to suggest the context in which the Bravo incident occurred. The "criticism" implied in the discussion of these a priori principles in no way applies to the responses to Bravo by the operator or the Norwegian government.

ACTORS INVOLVED AT BRAVO

Any crisis brings about a coalition of what would normally be seen as a diverse and disassociated set of actors. This was readily apparent in the Bravo incident; a system of actors united only by the impact of the disaster responded to the crisis [16]. The Bravo blowout not only brought diverse actors together temporarily to end the emergency, but also threatened to curtail all future offshore oil development north of latitude 62° N in Norwegian waters and to modify the regulations for such developments in the offshore areas of other countries as well.

Figure 2.1 places the major actor groupings into a system that shows the contribution of these groups in the overall response to the Bravo incident. The core actors are the Action Group, which formed the key regulator, and Phillips Petroleum, the key operator. The Action Group was an ad hoc body, it was not in existence prior to the blowout, although it had been under active consideration for some time [17]. This Group was created by the Environment Minister about six hours after the blowout occurred and it was given the necessary ad hoc authority to commit the Norwegian government to whatever actions and expenses were deemed appropriate in responding to the Bravo crisis. If feasible, major problems were to be presented to the Minister for decision. Four days later, on April 26, a permanent Action Group was formalized by Royal Decree to maintain a quasipermanent response to such accidents.

The Action Group's composition was based on the assumed needs of the situation at Bravo [17]: the State Pollution Control Authority to control oil pollution; the Oil Directorate to control oil flow; the Navy to provide transportation and personnel; and the Police to provide rescue and safety measures. Leadership was assumed by the Director of

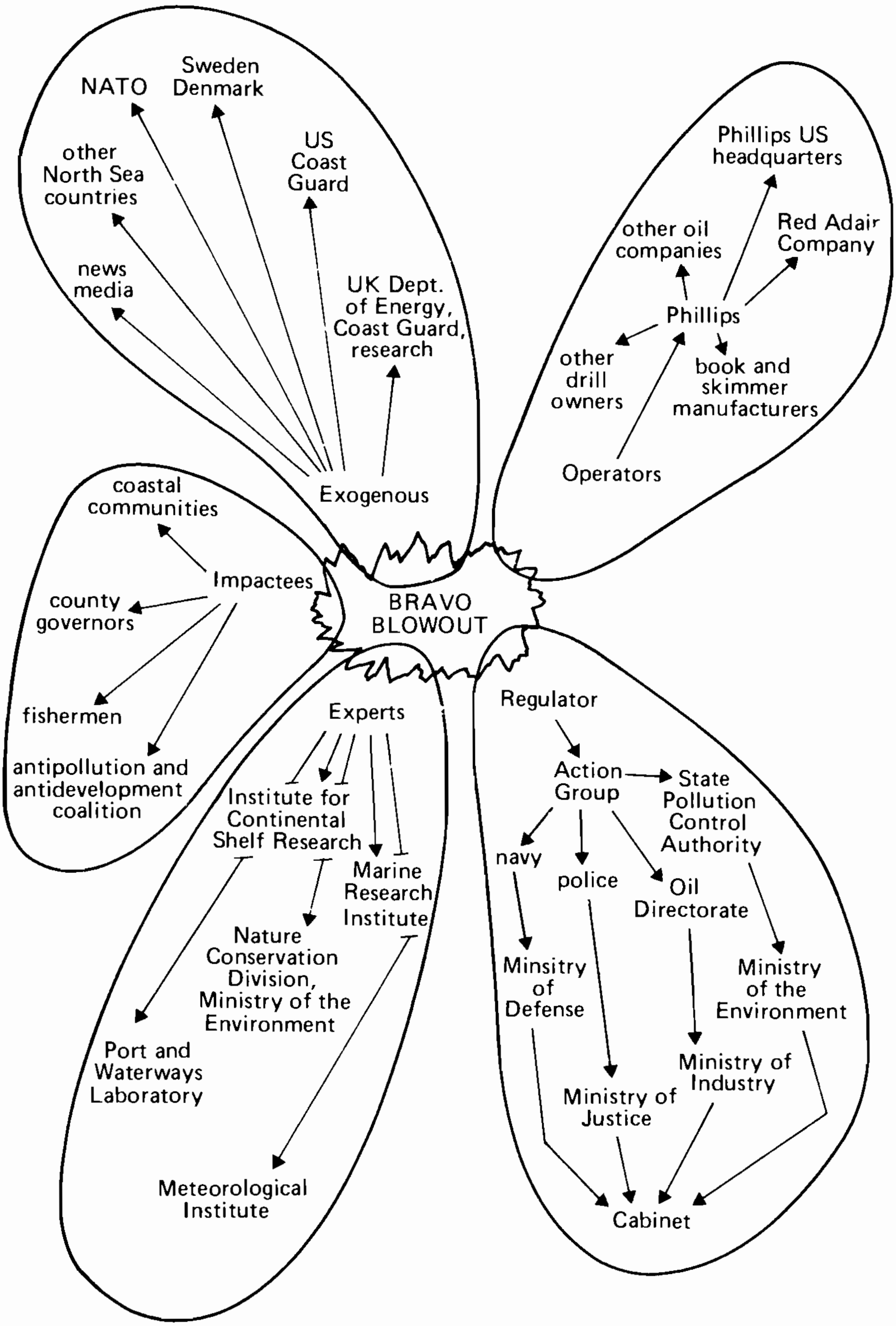

FIGURE 2.1 Actors involved in the response to the Bravo blowout.

the State Pollution Control Authority, who reported directly to the Minister of the Environment. A representative from Phillips Petroleum was appointed as liaison officer to the Action Group, and two meetings were held per day between the Action Group and the Directors of Phillips Petroleum Company, Norway. Had a tanker oil spill been involved, the Marine Directorate rather than the Oil Directorate would have been used. Later a representative from the Ministry of Foreign Affairs, who specialized in handling information for the foreign press, was attached as a liaison officer.

The Action Group can be viewed in the role of a networker, that is, it facilitated effective operation at interfaces by making the linkages of the network more effective [18]. In the present case, the network consisted of five different policy systems, three within national government and one from local government; the Action Group formed the focal point that represented all these systems. This reticulist group assessed the technological/environmental situation at interfaces. Though, by definition, a reticulist does not have decision-making authority, in this case the Ministry of the Environment granted the Action Group a mandate to make rulings that could affect the policy of all the systems represented. The judgments of this group were carried out through the appropriate organizations; therefore, the Action Group formed the hub of the decision network.

The tasks assigned to the Action Group were to assist Phillips Petroleum to control the oil flow at the well and to create a backup response for controlling and cleaning up oil pollution from the well. The first task was under the direct supervision of the Oil Directorate but was carried out by Phillips Petroleum who owned and operated the Bravo platform. The Action Group had no direct responsibility for the operations at Bravo; rather it surveyed and controlled the measures suggested by the operator [17]. The second task came under the aegis of the State Pollution Control Authority; it involved alerting other North Sea countries and coastal communities in Norway to possible impacts of the disaster and overseeing the response by Phillips to capture and contain the oil slick before it reached the coastline. This effort was also accomplished by direct supervision from a supplementary ad hoc government containment activity that involved a variety of personnel, equipment, and vessels from many different areas.

The Navy provided a liaison officer for the commander at the scene of the Bravo incident (himself also from the Navy) and also personnel and vessels for the oil-pollution containment, as well as direct supervision for these operations.

The police representative was the first member of the Action Group to arrive at the emergency rescue center, the base of the Group throughout its existence. His main responsibility was to supervise the rescue of platform employees from Bravo and to ensure that the Action Group had access to communications systems and other facilities. The task of personnel rescue, however, had already been accomplished without loss of life before the Action Group had assembled. This operation was carried out by Phillips immediately the platform supervisor had confirmed the existence of an uncontrolled well.

In its lead role the Action Group initiated the involvement of a variety of actors in the Bravo incident. Such actors were generally international experts, for reasons of both practical necessity and the need to disseminate information. For example, the US became involved because of its experience in such situations. The dissemination of information centered around estimates of the movement and degradation of the oil slick and the extent of actual or potential damages to marine organisms.

Each major actor subsystem was represented in the response to Bravo. However, the Fisheries Directorate was notably absent; this unit was given no direct authority in the activities, although its Marine Research Institute was involved. No other actors were directly involved in the Bravo incident, and none were considered necessary by the Director of the Action Group. The Bravo blowout was a national crisis, so any rivalries were quickly set aside in a cooperative spirit of national mobilization to meet any requirements it posed. Indeed, if any complaint can be made, it would be that too many organizations were involved in and with the Action Group.

Industry actors were not involved in the Bravo blowout except those of Phillips. Offers of assistance from industries with expertise and equipment were rejected except for a relief fire-fighting ship. (Such a rejection also occurred in the oil spill from the tanker *Amoco Cadiz* off the coast of France.)

For assessing damages and predicting the extent and direction of the oil slick, the Action Group relied on outside experts chosen solely from government research institutes on the basis of their scientific reputations.

Exogenous or international involvement was based on the Bonn Treaty of 1969, which requires a North Sea country that has had an oil spill in its waters to inform other North Sea countries. In addition, the Action Group gave special attention to the UK, the Nordic Community, and the USA. The UK Coast Guard was alerted and later the UK Energy Minister flew to Norway to survey the situation and offer assistance if needed; however, the main UK response was based on chemical dispersants and not on mechanical containment, so that no compatible response system existed between the two countries. Sweden offered assistance, which was accepted; the Swedish Coast Guard provided two vessels, booms, and skimmers. Denmark, which was threatened by the expanding oil slick, sent an observer to the Action Group, lent much of their oil-containment equipment, and made several aerial surveys of the oil slick. In addition, a Danish vessel stayed near the oil slick to combat it if necessary. American aid was to be in the form of air-transported teams with skimming equipment and trained operators, but such equipment was only of value in waves under five feet. Two US Coast Guard observers came to Norway to assess the situation. No use was made of these US teams, because the oil flow was stopped before a final decision had been made on US assistance.

The only uninvited actors attracted to the Bravo incident were foreign newsmen and a Norwegian antipollution group hostile to further offshore oil development. The involvement of this group was limited to an alternative press conference at the time of the incident, although this did serve to focus the attention of foreign and Norwegian news media on the larger issues that surrounded petroleum development; such issues were drilling north of latitude 62° N and the effects of day-to-day operational oil pollution from offshore platforms. The group had no direct interaction with the Action Group.

The foreign news representatives, who eventually totalled around 150, posed special problems for the Action Group; their demands for information were incessant, and part of the effort had to be diverted to satisfy this demand. However, representatives from the Ministry of Foreign Affairs eventually assumed this liaison role. Problems included the sheer number of reporters, the variety of information demanded, their ease of access to the working area of the Action Group, their demands for up-to-date and background information, their deadlines for presenting material, the fact that Norwegian reporters often had access to information before it had been given to the Action Group (which also, incidentally, aroused criticism about the supposed withholding of information from foreign reporters), and chartering of aircraft to view the Bravo blowout even though this could have interfered with operations to control the well. This last problem was countered by the creation of an air safety zone around the Bravo platform.

ALTERNATIVES FACING THE ACTION GROUP

Several key alternatives were open to the Action Group, including decisions of timing. The first set of alternatives concerned organization of the Group in relation to other governmental bodies, and to Phillips Petroleum. Figure 2.2 shows the Action Group in relation to other important organizations associated with Bravo. As is readily seen, the Action Group played a central and authoritative role in combating the oil blowout at Bravo.

The Group checked plans formulated by Phillips to deal with the blowout and the resulting pollution. Afterward Phillips was asked to prepare a new plan to meet additional criteria put forward by the Action Group. This draft plan was prepared and presented to the Oil Directorate, who checked the technical aspects of the draft. Then Phillips presented this revised plan to the Action Group for approval. After the Oil Directorate confirmed feasibility, final approval was given by the Group. Constant monitoring of Phillips' operations was also undertaken.

The Action Group also monitored Phillips' pollution-containment and well-control efforts closely. A plan drawn up jointly by the Action Group and Phillips was used to contain oil after implementation by the Navy who acted as the site supervisor. Finally, the Action Group directed and coordinated government efforts to support the Bravo operations.

The other role of the Action Group was coordination. This coordinating role allowed Phillips Petroleum and the Oil Directorate to play more active parts in the response to the blowout. Without this facility the government must, of necessity, have been more passive in responding to initiatives from Phillips, and emphasis would have been on controlling the blowout, a much smaller effort being put into pollution containment. Violation of established government principles would also have been more possible.

The direct authoritative role taken by the Action Group stemmed from the established principle that the government can take over the operation if it deems the risk of great damage to be present [19]. Thus, the operator was aware that the government could take over company operation at any time. Before the formation of the Action Group, Phillips Petroleum was already engaged in personnel rescue, fire prevention, control of pollution by chemical dispersants, and assessment of well-capping possibilities.

The alternative strategies and resources available for blowout prevention, well and pollution control, and cleanup were presented in Chapter 1. These alternatives were presented partly to show what options were available to the Action Group in their attempt to control the Bravo blowout. However, another series of "alternatives" was important in determining the appropriate responses, particularly for well and pollution control – the adverse events that might have occurred at the Bravo blowout if a similar blowout had occurred at another location and time. Some of these adverse events were noted in Chapter 1.

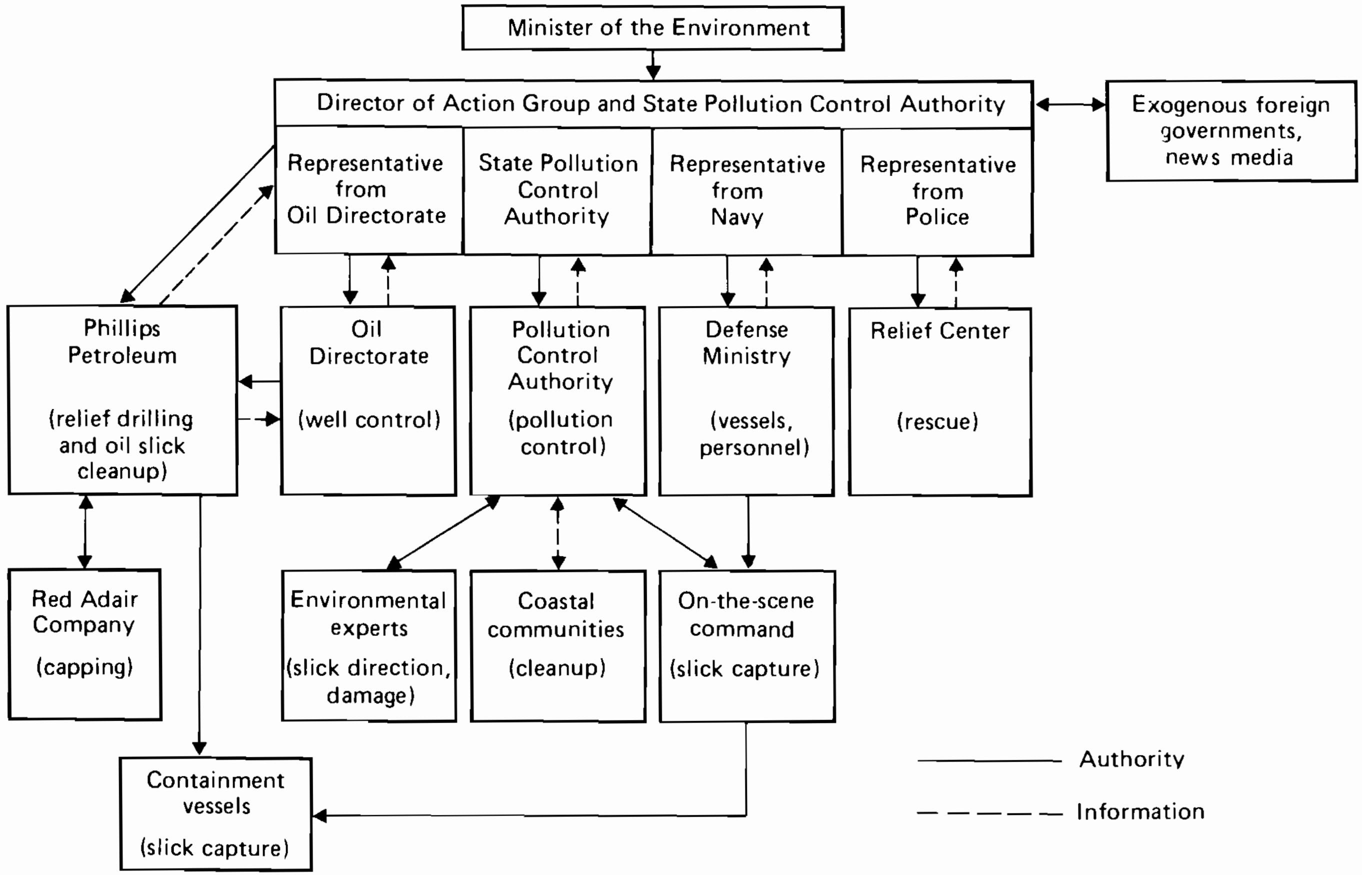

FIGURE 2.2 Organizational relations of the Action Group with other major actors involved at Bravo.

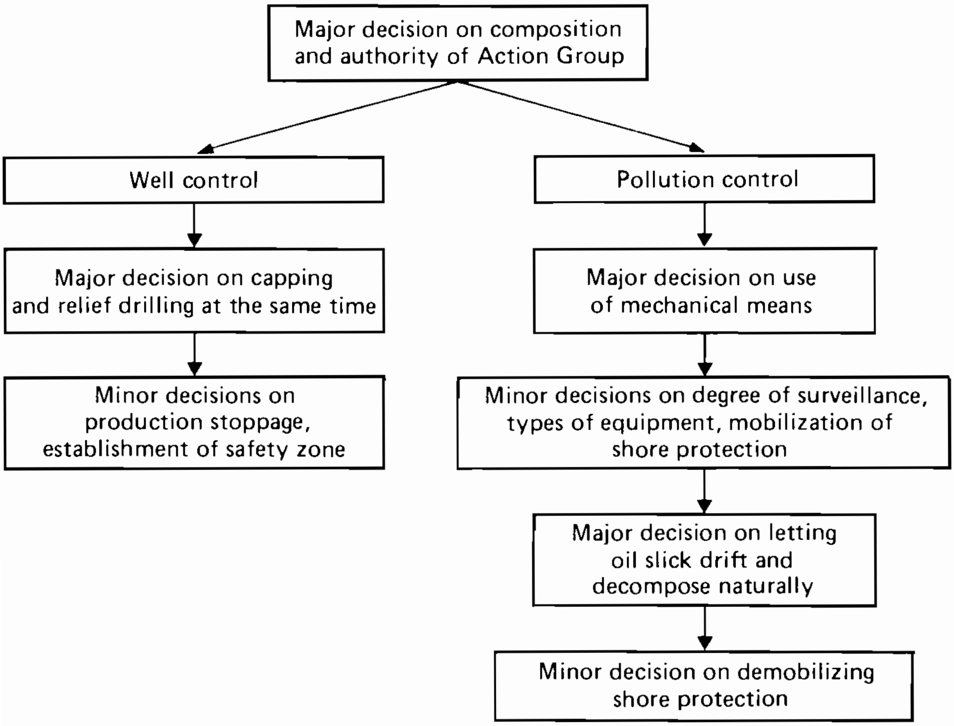

FIGURE 2.3 Outline of major and minor decisions of the Action Group established to combat the Bravo blowout.

While it would be interesting to construct a decision and event tree of the possibilities, no adverse events actually took place during the Bravo blowout. In fact, in the judgment of the Director of the Action Group, the response to Bravo had already reached its practical limits. Had any combination of other events been present and coupled to the responses chosen, far greater difficulties would have been experienced and damage would have been more extensive. Clearly, the Bravo event in itself provided a valuable "training exercise."

DECISIONS MADE AT BRAVO

The decisions made at Bravo were significant in that they established the pattern of Norwegian responses to oil blowouts. Principles of operation were both established and confirmed. The basic decisions listed in this section were provided by the Director of the Action Group as well as by the preliminary report of this Group to the Minister of the Environment. Figure 2.3 shows an outline of these decisions.

The first major decision was the appointment of the Action Group by the Minister of the Environment, including the necessary authorization to make decisions in the name of the Norwegian Government. This decision, of course, was basic to the entire operation. The Prime Minister provided his personal backing to the Action Group and the Minister of Industry and the Minister of the Environment together gave their support. Thus, the leading government representatives of the development and environment policy systems were unified in responding to the crisis. The Director of the Action Group was also the Director of the State Pollution Control Authority, so that the Group functioned under the immediate direction of a representative from the environment policy system who, in turn, reported directly to the Minister of the Environment. Therefore, although a union was formed between government development and environmental core actors, the environmental actors played the lead roles. The basic premise was that the Bravo blowout was a national emergency that required a unified national response. This key decision on authority and unity led to the formation of the ad hoc Action Group, which formed the basis of the Bravo response. This initial decision was further corroborated by the Norwegian government when it established the Action Group as a permanent body four days later [23].

The implication of this decision not only guaranteed a unified response by government but also established a command relationship with Phillips Petroleum. Under previous principles, the owner and operator of a platform was solely responsible for responding to a blowout and for meeting any associated crisis. Phillips in theory was therefore obliged to take whatever steps were necessary to stop the blowout and to restrict damage from it. In addition, the company had to accept unlimited liability, including liability for such actions taken by the government as it considered necessary. This liability position was reconfirmed by the Action Group.

What had not been decided or known prior to Bravo was whether the operator or government would take the lead role in responding to the crisis. All that had been known a priori was that government could take over the management of the crisis if the situation so demanded. No guidelines existed to define these circumstances. The government, in accordance with this established principle, decided immediately to guide the overall operation and to direct Phillips' responses to the blowout. Thus, the company became subordinate to the government, even though it had to carry out the work and pay for the entire operation.

Few problems were encountered between the Action Group and Phillips, as the company accepted its subordinate role, its responsibility, and its open-ended liability. Phillips' attitude toward the Action Group was described as "good." The quality of the information flow from Phillips to the Action Group was well maintained through Phillips liaison officer and twice-daily meetings with the Action Group. However, initial information received from Phillips about the Bravo platform and the capping process was described as "too vague." In addition, Phillips was seen as slow in informing officials about the blowout in the first place.

The Action Group had the following tasks: to keep itself informed about events as they happened; to evaluate Phillips' plans and actions; to create guidelines for the work necessary; to give the necessary orders and concessions to Phillips; to decide who would participate for the government; and to organize a staff to support the effort [23].

POLLUTION-CONTROL DECISIONS

The second major decision made was a result of the authority assumed by the Action Group in relation to Phillips. This was that mechanical techniques rather than chemical dispersants were to be used to stop pollution. Much time was spent in discussing this issue. It was finally referred to the Minister of the Environment for final approval because of its signal importance. The decision had implications about the scale of effort, and hence about the expense necessary to combat pollution, as well as the increased risks of oil reaching the coastline owing to delay in getting mechanical devices in place and their unproven operational feasibility. A precedent was also being established for future operations connected with major oil spills. Political risk was involved as Norway has a strong political commitment to its fisheries and fishing industry. A judgment of "no chemicals" gave continued political support for the established principle of mechanical containment. Reliance on mechanical means is in accordance with the statement [24] that "present levels of knowledge and experience do not truly allow a decision concerning dispersant use to be based on scientific fact."

In its investigation of Phillips' plans and actions the Action Group found that the company had no mechanical equipment or trained personnel available, either offshore or in Norway. In fact, Phillips had only chemicals available for meeting oil pollution from its offshore platforms; the company was relying solely on chemicals to disperse oil pollution [13]. This reliance on chemicals, however, was an interim measure until the company was able to comply with government regulations passed in November 1976 to have available an oil pollution cleanup capacity of 8,000 tons per day. The blowout occurred during the period between government passing the regulation and implementation by the operators [13].

During the first twelve hours after the blowout, Phillips used chemicals freely in an effort to disperse the oil. The company stopped only when ordered to do so by the Action Group the day after the blowout [25]. Around the platform itself, however, permission was given for the continued use of chemicals to disperse oil, which could be a fire hazard. As a backup measure Phillips was allowed to bring supplies of chemicals and spray vessels to the area for use if deemed necessary by the Action Group. Phillips requested approval from the Action Group for combined use of mechanical methods and chemicals; however, after discussion with scientists and other experts a ministerial decision was made to prohibit the use of chemicals. Therefore, Norwegian officials judged that the impact of potential coastal pollution would be less than the impact associated with the use of chemicals on the high seas.

Control over the chemicals actually used by Phillips proved to be difficult. Although the company reported the use of only 55 tons of two types of chemicals in total, it was not possible to check this figure, and for safety reasons no restrictions were placed on the amount of chemicals used to disperse oil around the platform itself. Spraying at night occurred, but it was claimed that no checks were possible.

Since the Action Group placed total reliance on mechanical methods, several lesser decisions and efforts became important. They involved the accuracy of surveillance and forecasting of decomposition and movement of the oil slick, the types of mechanical equipment to be used in the attempt to collect the oil, and mobilization of coastal protection resources.

Two flights were made daily to observe and photograph the oil slick. In addition, naval vessels were dispatched to take charge of the collection effort and to report on decomposition, spread, and movement of the oil slick. Phillips mounted its own aerial effort to follow the development of the slick; an aircraft, while being traced on radar by a Navy command vessel in the vicinity, followed the contours of the oil slick.

A key problem in surveillance was the number of aircraft from other nations that were monitoring the oil slick. In addition to Norwegian air surveillance, at any one time Swedish, Danish, West German, British, and NATO aircraft could be in the vicinity, each plotting their own estimates of the slick's movement. Inevitably these estimates did not agree, but, more importantly, air traffic control was complicated by the differences that existed in the definition of a safe air zone, i.e., minimum offshore altitudes over platforms and safety zones in Norway differ from those in the UK. Some interference of Norwegian surveillance occurred because of the presence of foreign aircraft.

The gradual thinning, spreading, and breakup of the slick into patches meant that a greater surveillance effort had to be mounted to maintain the initial degree of accuracy. The Action Group decided not to attempt to maintain this accuracy but to describe the slick in more general terms. This decision was corroborated by the fact that no foreign aircraft reported the slick beyond the area estimated by Norwegian sources. After the blowout was stopped, a detailed air reconnaissance was made over the area assumed to have been affected or reached by the slick. Only small oil patches were seen in some limited areas, so that no mechanical collection was deemed to be worthwhile. Larger areas contained a thin film that was decomposing naturally.

In addition to aircraft surveillance, a mathematical model was used to predict the drift of the oil slick. The first version of this model was produced in April 1977, just a few days before the Bravo blowout occurred. This blowout provided a test for the model and daily computer runs were made and used by the Action Group in planning the cleanup operations [26].

The next minor decision proved to be of considerable difficulty: what types of booms and skimmers to employ. The mechanical equipment available in Norway for use in coastal waters was flown to the Action Group's center of operations. Both company and Norwegian aircraft and vessels were used to transport booms and skimmers to the site of the operation. In addition, two Swedish Coast Guard vessels with booms and skimmers were requested. Many other offers of equipment were received by the Action Group from foreign sources. The group decided to reject these offers temporarily and use only the equipment it knew best. Norway had already developed coastal protection booms that had been tested in the open sea in good weather. Other equipment had been ordered but never tested.

The greatest problem in using the equipment was the difference in performance between that claimed by the manufacturer and that observed in actual use. The equipment available had a combined total theoretical capacity of 7,000–8,000 tons of oil per day, which exceeded the estimated flow of oil from the blowout. Only a part of this equipment was initially employed, and it collected 20 tons of oil in its first day of use [27]. Thereafter, the equipment was reported to be 25% effective under the most ideal conditions. Other equipment rated at 4,000 tons per day collected only 100 tons per day. Equipment used by Phillips with a quoted capacity of 1,800 tons per day was also only 25% effective. Four Vikoma skimmers developed in the UK by British Petroleum and employed by Sweden each had a theoretical capacity of 300 tons per day but only collected 60 tons in total during the time they were used [13]. The only skimmer that approached its quoted capacity when operating in three-meter waves had been designed and built in Norway but never tested prior to its actual use. In all, eight different types of boom and three types of skimmers were tried.

The emulsified oil collected by this equipment totaled 1,700 cubic meters and contained 935 cubic meters of oil (about 800 tons) [1]. The greatest amount collected in a single day was 800 cubic meters, while the least was 60 cubic meters. The total amount of 800 tons of collected pure oil is insignificant, of course, when compared with the 13,000 tons of oil which escaped into the water. Although waves were high and the weather bad for efficient operation of booms and skimmers, storm conditions were not experienced; most of the equipment simply failed to work in the open sea under less than ideal conditions [13].

Another problem with this equipment was the number of small units to be brought together and deployed in an effective manner. Transport, booms, skimmers, and personnel had to be found and matched to form a unit capable of containing and collecting the oil. Vessels suffered maintenance problems, some had insufficient crew, and some were too underpowered to remain in place on high seas. Booms and skimmers of different design were difficult to put into place and match. Insufficient numbers of effective booms and skimmers were available for use even if conditions had been ideal. The slick was characterized by patches of oil extending over an area of 1,500 square kilometers. Only 6,100 meters of boom were actually used to combat these oil patches or kept on standby. Phillips ordered 2,000 meters of booms, but only 100 meters per day could be produced. Finally, personnel were generally untrained in using such equipment. A training period is essential if personnel are to use the equipment effectively. Differences of opinion exist over whether the equipment was ineffective in itself or rendered ineffective through inadequately trained personnel. At present an assessment is under way to determine the effectiveness of the equipment, vessels, and communications used [13].

Coastal-protection mobilization was necessary because of the major decision to reject chemical dispersion of oil in favor of mechanical collection. The coastal communities were informed by the State Pollution Control Authority that an oil slick was approaching the Norwegian coast. The Oslo center of the Agency acted to coordinate community efforts to protect the shoreline. Communities were instructed to review their resources, establish emergency plans, and specify areas to be protected. The government also guaranteed to cover the expense of establishing emergency measures and participating in the protection and cleanup operations. Reimbursement for the purchase of equipment was, however, not guaranteed. This decision was made to stop various communities from ordering and buying equipment and thus temporarily blocking the production of other equipment more urgently needed at sea.

It was initially assumed that the oil would reach the coast by April 26, although it was not until May 2 that the entire coastal area liable to be affected was organized. Communities were kept informed about the movement of the slick by the Action Group via its Oslo office. County Governors were used as liaison officers. Emergency protection areas were designated with the aid of the Nature Conservation Division of the Ministry of the Environment. Plans were then prepared for moving personnel and materials to and between these emergency zones. A joint plan was finally prepared to provide the areas to be protected with available supplies and equipment. Soon after the organization had been completed, a demobilization order was issued. Some criticism was directed to the national government, but the Bravo blowout showed that communities were generally ill prepared to respond adequately to a coastal oil threat.

The other major decision associated with pollution control was to let the oil slick drift and naturally decompose at sea, no attempt being made to collect it mechanically or disperse it chemically. This was in effect a "nondecision," since although the Action Group did not approve this course, it was necessitated by the sheer impossibility of coping by mechanical methods. Once the slick thinned and broke into isolated patches over a wide area of sea, it was too expensive to use mechanical devices in an efficient way. These factors dictated the decision to let the slick drift, which was reinforced by a prognosis that the slick would remain at sea, disintegrate naturally, and not reach the coastline. Finally, only the use of chemical dispersants would have been cost-effective at this stage, and such a course had already been ruled out on political grounds, although this decision could have been reversed had the slick approached the shore.

The action of the sea caused the slick to evaporate and disintegrate. On May 3 it was estimated that in another five to six days the oil would have completely disintegrated; therefore, the final minor decision was to demobilize the coastal protection service on the estimated day. Some risk was involved in this decision, but forecasts of the weather and movement and decomposition of the slick were such that the costs involved in maintaining a major state of readiness could not be justified.

WELL-CONTROL DECISIONS

The other major decision that stemmed from the authority of the Action Group in relation to Phillips was associated with well control. Phillips was ordered to present a well-capping plan and to start drilling a relief well [1]. Such an ad hoc well-control operation was necessary because no other plans existed [28].

On its own initiative Phillips requested the assistance of the Red Adair Company from the USA, specialists in controlling oil blowouts. It took 24 hours for a team to arrive at the Bravo platform. For the first 36 hours after the blowout, no attempt had been made to control the oil flow. Since the general view is that each blowout is unique [29], well-control equipment is not standardized, and hence no stocks exist.

With the assistance of the Red Adair Company, Phillips' engineering staff drew up a capping procedure. Both the Oil Directorate and the Action Group approved the Phillips–Adair plan, which however proved difficult to implement because the surface BOP had been installed upside down [30]. This mistake necessitated modifications to the well-capping equipment. After several abortive efforts, further modifications were successful in closing the well and mud was then pumped in to stabilize the pressure. When brought under control at 17.45 on April 30, the well had been in an uncontrolled state for nearly eight days, spilling up to 22,500 tons of oil into the North Sea (the actual amount may be significantly less than this figure).

Simultaneously with the capping operation Phillips were trying to locate a suitable rig, which could be towed to the Bravo site and used to drill a relief well. Such a well, which relieves pressure buildup in the reservoir, must be close to the uncontrolled well. Two days after the blowout a jackup rig was located and hired; however, the weather conditions would not allow the rig to be moved. After nearly four days, during which several unsuccessful attempts had been made to move the rig, the Action Group ordered Phillips to bring in a semisubmersible rig in addition to the jackup rig. It was arranged for such a rig to arrive on site on May 1. Since the blowout was controlled on April 30, Phillips' request to cancel drilling of the two relief wells was approved by the Action Group just 15 minutes after the Oil Directorate declared that the blowout was under control [30].

Production of oil and gas from other wells on the Bravo platform was stopped automatically through their BOP systems. The policy on production in the Ekofisk field as a whole, however, had to be decided. A code existed for stopping production, but only under specified weather conditions or when gas concentrations had built up to critical levels. Oil blowouts were not included in this code and it had not yet been decided whether the entire field should be shut down during a blowout. However, the Action Group established its own code for stopping production, based on the fire risk involved, and this was agreed to by Phillips. Production had actually been stopped several times in the past owing to adverse weather conditions.

The Norwegian government decided independently that all production from the Ekofisk field must cease [30]. The Action Group and the Oil Directorate were informed of this decision. Although this matter had been considered by the Action Group, neither its advice nor that of the Oil Directorate were requested by the government in advance of this purely political move. The government wished to allay criticism by taking what it considered firm, positive action. Once the blowout was under control, the entire Ekofisk field was working within four hours.

The last minor decision about well control was to establish a safety zone around the Bravo platform. This was necessary to ensure good working conditions around the platform and avoid the possibility of other accidents in the immediate area. The zone declared under the Continental Shelf Convention was defined as a free space of radius 500 meters from the platform, with no air-space restrictions above it. Creation of this zone was a source of confusion to foreign observers in aircraft, particularly to television and press reporters, because it was defined in wider terms by the Action Group. The latter established a zone of radius ten nautical-miles, with air-space restriction to a height of 5,000 feet above the platform itself. The various national definitions of air space, on which unilateral decisions can be made, make the creation and recognition of such zones difficult. Clarification of this issue is a matter of some urgency [30].

EVALUATION OF THE BRAVO RESPONSES

Evaluation of the activities and decisions surrounding the Bravo incident can be made on several bases: lessons learned by the Action Group itself, comments from critics and observers, and the position as evaluated by the present author.

The Action Group formed a focal point for the Bravo operation and learned many lessons during its short life. Such a group had never previously been assembled to handle a blowout emergency. The experience gained is summarized below [31].

Organizational Evaluation

The authority given to the Action Group was confirmed as the best organizational form.

The creation of a body to advise the Group on industrial disaster experience was useful. The fact that the response of an oil company to a blowout differs according to where it occurs was learned – a previously unknown factor (e.g., in the UK a Clean Seas Committee has been formed by oil companies to act as a clearing center for cooperation, whereas in Norway no such body existed nor did other oil companies provide help to Phillips).

The experience showed that no common approach to blowouts exists among countries in the North Sea area.

The need was seen for specialist companies such as the Red Adair Company to allow government observation of their work and to arrange procedures for effective cooperation.

Information Evaluation

It was recognized that there is a paramount need for more reliable information about the performance of mechanical equipment for controlling pollution in the open sea under all the weather conditions likely to be experienced.

A special VHF radio disaster communications channel was seen as a necessity, since the Action Group had to rely on emergency frequencies that are also required for other rescue purposes.

Greater research on the effects of large amounts of oil in the water column was seen as important for predicting and assessing damage.

Equipment Evaluation

The lack of options was a problem, so there is a need for government and the oil industry to develop these for more effective blowout management.

There is a need for a failsafe manually operated BOP, i.e., either it should work in either position or be impossible to fit upside down.

There is also a need to re-evaluate mechanical equipment for pollution control in the open sea, e.g., such equipment must be capable of efficient operation even close to the blowout, have a capacity to remove large amounts of oil in all weather conditions, and be in the form of a single self-contained unit.

It is important to adopt a training program for operators of fire prevention, capping, and pollution-control equipment.

Standards for pollution-control equipment must be adopted on a uniform international basis.

The Director of the Action Group felt that the timing of the blowout and the weather conditions prevailing at the time were fortunate. Had the blowout occurred earlier, it would have had a major effect on the migration of seabirds, particularly auks; had it occurred later, a major spawning ground for mackerel would have been affected. The accident also happened during the period of maximum daylight – nearly 24 hours per day.

The failure of booms and skimmers to approach their specified performance was a great surprise. Clearly, the testing, rating, and specifications of such equipment leave much to be desired. Even taking this into account, however, there is still a need for the complete re-evaluation of such equipment. The greatest satisfaction was expressed by the Director of the Action Group that, during the entire crisis, no loss of life occurred. In addition, the platform itself and the equipment used in the operations did not suffer extensive damage or loss.

The overall assessment of the Director was that the best was done under the circumstances and that the efforts of the entire country were united to control the blowout. The operation, however, was not without criticism both at home and abroad. An anti-oil group, rather than focusing attention on the blowout per se broadened their attack by including oil development as a whole. It must also be taken into account that 1977 was an election year in Norway and the government in power was in a minority position.

The Norwegian government appointed a commission to investigate criticism of Phillips' actions at the Bravo platform before and during the blowout. In addition, the government set aside a day in Parliament to debate its handling of the crisis. Finally, a white paper summarizing all aspects of the Bravo accident was prepared [32].

Both Norwegian and foreign critics have suggested areas where the government effort could have been improved and these are summarized below.

Relations with Phillips [33]

Both the Norwegian government and Phillips have a financial interest in operating the Ekofisk field at maximal levels. This might affect decisions made during a crisis.

Oil Directorate personnel were neither on the platform when the blowout occurred nor during the incident until after control was regained; therefore, little government knowledge is available as to Phillips' possible negligence (if negligence is proven royalties must be paid on lost oil).

Legal unlimited liability of the operator gives a false sense of security since there are many ways of circumventing this provision.

Since the operations of Phillips in the Ekofisk complex were subject to government vetting, the government could be held responsible for the blowout. It was common knowledge that Phillips did not have adequate capping and containment equipment.

The government did not follow up workers' complaints that Phillips was not following security regulations and had inadequate security plans.

Research Efforts [34]

The long-term effects of an oil slick on marine life are not well known [35]. If oil remains long enough on the water surface and in the water column in concentrations above a critical level, the emulsified oil kills plankton and the eggs and larvae of fish; if the oil evaporates or is dispersed rapidly into a large body of water, less harm is done to marine life, since there is less likelihood of critical concentrations being attained.

The results of studies by Norwegian research vessels were not available prior to the blowout. During and after the incident, these vessels took samples from the vast spill area, obtaining the data on which the claim of minimal damage was based.

The effects of the slick on birdlife are contradictory. Although the total number of birds lost was estimated to be fairly low, British reports indicate larger numbers of seabirds were killed than is quoted in Norwegian reports.

Research and development has been focused on the structural design of platforms.

Operational Efforts

Statements put out during the blowout did not give a clear account of what was happening. Does "amounts collected" mean oily water or oil? What is meant by "safety criteria"? Why do differences exist in wave-height figures? What kinds of chemicals were used and how were these applied? Many other queries could be raised.

Conflicting views are held on the use of subcontractors to operate platforms, their training, and their safety procedures.

EVALUATION OF THE DECISION PROCESS AND ITS OUTCOME

It is of vital importance to have a comprehensive, integrated plan to protect the environment during an oil disaster [36]. This section examines to what extent this condition was met during the Bravo crisis.

A comprehensive plan must consider the contributions that each actor group can make to alleviate the situation. Actor groups in the present case would be operators, regulators, experts, impactees, and exogenous actors. An integrated decision process places these actor groups in such a way that feedback from all other groups are taken into account before a decision is made. These concepts have been applied to Phillips and the Action Group, since they were the key actors in the Bravo incident. The decisions made by Phillips and the Action Group can be assessed for comprehensiveness not only on the basis of who was involved but also on whether information from such activities as research, planning, operations, information flows, and monitoring was sought and used. If these same activities, which are necessary to environmental management, were affected by decisions made, then such decisions can be seen as comprehensive. Integrated decisions affect environmental-actor regulations and procedures, as well as development-actor designs, plans, and operations.

Table 2.1 lists the basic decisions involved in the Bravo incident, together with the originator of the decision and the outcome. This summary also gives a qualitative evaluation of each decision, others reviewing these decisions may arrive at quite different evaluations.

Clearly, the Action Group was a comprehensive unit that merged the technical and environmental policies under the overall direction of the Minister of the Environment. Its decision process was thus to review the elements of both policy systems and feed the conclusions directly to the political decision maker for the environment. The Action Group was an integrating force between the two separate policy systems, while itself being integrated with the operator of Bravo via its authority over Phillips. Therefore, decisions were made readily and followed up easily.

Through its linkage to the environmental-research and monitoring actors, when necessary the Action Group was able to utilize these resources very quickly. Damage to fisheries and birdlife was assessed by the Marine Research Institute, while forecasts about the oil slick were made by the Institute for Continental Shelf Research. The Action Group was also instrumental in allowing international observers to view the operation and gave advice on combating the oil slick. Unproven alternatives to the proven chemical methods of oil dispersion were only attempted on such a large scale because the Director of the State Pollution Control Agency was a member of the Action Group. Therefore, the composition and position of the Group in the decision-making hierarchy, together with its willingness to attempt alternative strategies, indicate its comprehensive, integrated position in the decision process.

The outcomes of the decision process also reflect the nature of the Action Group; the initial approach of Phillips to both well and pollution control was radically altered by the Group. It also changed the government's view of the state of preparedness that existed to combat the situation and stressed the need for a single comprehensive government agency, integrated into the decision-making process, to deal with emergencies. Research on damages caused by oil, pollution control, well control, and blowout prevention have all been strengthened by the Bravo emergency. The Action Group played an important role in fostering this research.

Phillips Petroleum, on the other hand, did not exhibit a comprehensive decision process. It did not attempt to link its well and pollution control with that of the government until ordered to do so. This does not imply a deliberate lack of cooperation with the government, but rather a "going-ahead-alone" approach, which relied solely on what it understood best, the industry response. This approach stressed the urgency of obtaining personnel and a rig to combat the emergency; chemicals would then be used to disperse the slick, and the specialist Red Adair Company would cap the well. No expertise was available in the Phillips organization itself to cap the well and no mechanical equipment for pollution control was available.

The strategy of Phillips Petroleum was comprehensive and integrated as far as securing the platform and saving lives was concerned; outside specialists were also contacted with minimal delay. This is in marked contrast to its approach on environmental issues, which was not in accordance with government regulations. No experts on the environment were brought in by Phillips before or during the blowout. No alternatives for pollution control were envisaged. However, measures were taken to set up an independent monitoring effort to assess damages in the open sea from the oil slick. The design of the well system completely ignored environmental factors.

Table 2.2 is a summary of the responses to Bravo generated by each of the key actor groups. Little new information is contained here; rather a convenient format is used to display important items from the text. The table does show, however, the uncertainties and conflicts that surrounded the choices of criteria available to the key actors.

Two striking points are the disappointing performances of the pollution-control equipment and the lack of knowledge about likely damage that would be caused by the

TABLE 2.1 Outline and evaluation of the Action Group decisions, their origin, and outcome.

Decision		Origin of decision	Outcome and comments	Evaluation
1.	Create Action Group	Fiat of Environment Minister	No previous existence, multi-institutional organization; one government focal point	Comprehensive set of agencies; integrated unit for environment
1a.	Authorize use of Action Group	Same as above (later agreed to by government)	Direct operations; better information; reduced mismanagement	Comprehensive government role, integrated with operator
1b.	Notify foreign governments	Action Group	Compliance with Bonn Convention; outside aid and advice sought	Comprehensive involvement; integrated aid and advice
1c.	Notify news media	Action Group	Information provided; criticism from outside reduced	Integrated information with government view
2.	Effect well control	Phillip. Action Group, Oil Directorate	Well controlled; new prevention and response effort	Comprehensive approach
2a.	Carry out capping and drill relief well simultaneously	Action Group, Oil Directorate	Earlier consideration of relief well; wider perspective; greater expense; shorter time to control	Integrated alternatives
2b.	Stop production	Action Group, Phillips, government	Concern and action explained to public; reduced risk of another blowout; revenue delayed	Integrated accident with entire Ekofisk field
2c.	Establish wide safety zone	Action Group	Air space controlled; conflicts over air space; work space ensured	Integrated observation with well control
3.	Effect pollution control	Action Group, State Pollution Control Authority, Ministry of the Environment	Phillips' plans changed; pollution not controlled; new response effort; more research	Comprehensive attempt
3a.	Rely only on mechanical methods	Action Group, experts, equipment manufacturers	Chemical risk assumed worse than oil risk; risk taken with unproven means; unable to rely on UK aid; unable to follow Phillips' plan; time loss to find equipment, higher costs	Comprehensive perspective on environment; integrated with fishery emphasis

TABLE 2.1 *(continued).*

Decision	Origin of decision	Outcome and comments	Evaluation
3b. Establish degree of surveillance	Action Group, Ministry of Defense, research experts	Direct, accurate data on slick size; forecast of slick direction; slick composition and disposition determined; damage assessment and prediction	Comprehensive approach, integrated data sources and means, research and operations
3c. Use booms/skimmers	Action Group, suppliers, Phillips, foreign governments	Equipment ineffective; oil not collected; pollution threat remained	Problems of integration of effort at scene, lack of integration with suppliers; comprehensive view of equipment fit
3d. Mobilize coastal cities	Action Group, State Pollution Control Authority, Ministry of Environment, cities, counties	Prepared for impact; deficiencies incurred; expenses	Comprehensive preparation; integrated response along coast; integrated sea effort with coast effort
4. Let slick drift	Action Group, experts	Assumed slick stays at sea; assumed sea discomposes slick; some pollution threat remained	Integrated response with environment's ability to assimilate oil
4a. Demobilize coastal cities	Action Group, experts	Small risk of oil coming later incurred	Integrated sea effort with coast effort
5. Investigate and assess accident	Ad hoc independent government commission, Action Group	Determined cause and if negligence; better response in future	Comprehensive overview; integrated future response

TABLE 2.2 Summary of actor responses to Bravo accident.

	Accident response group(s)	Normal regulator(s)	Operator	Experts	Impactees	Exogenous
Key actors	Action Command (ad hoc)	Oil Directorate Pollution Control Authority	Phillips Petroleum	Military Institute for Continental Shelf Research Marine Research Institute Saga Petroleum	Central government Coastal communities Fishermen	Nordic countries News media Other oil companies
Key areas of choice	Supervise Phillips Support Phillips Contain consequences Public information	Support Action Command Assess Phillips plans Obtain pollution oil equipment Alert communities	Prevent blowout Stop blowout Control pollution Protect life and property	Provide transport, personnel Forecast oil slick Assess damages	Display good response Protect shore Protect livelihood	Aid to Norway Responses if prolonged accident Understanding of and access to information Cooperation with Phillips
Associated choices	Internal organization Assess alternatives Take over operation	Responses to prolonged accident	Production on other wells Find and use equipment Determine procedure	Responses to prolonged accident Assess alternatives Research	Future oil production Remain in power Preparation for slick Remove vessels	Gain new information Public right to information
Associated actors	Ministries Politicians	Ministry of Industry Ministry of the Environment	Red Adair Company Pollution Control Equipment Manufacturers	Other research institutes Foreign colleagues	General public	Other North Sea governments NATO Outside experts
Choice criteria	Retain established principles Ensure public protection Show government in command	Ensure competent management Ensure readiness to meet pollution	Guarantee good relations Minimize liability Minimize losses, costs	Proven research results Try new research model	Economic base Future of party Resource allocation Future of catch	Contain pollution to North Sea Test own pollution control equipment Headlines Heighten public awareness

TABLE 2.2 *(continued)*.

	Accident response group(s)	Normal regulator(s)	Operator	Experts	Impactees	Exogenous
Uncertainties	Impact of slick (Pollution, public) Disposition of slick Management of slick Timing of well control Use of research	Timing of well control Performance of equipment Coastal protection	Performance of equipment Government demands Future government responses	Performance of equipment, crews Damages from slick Predictions of drift Acceptance of results	Harm to party Harm to oil program Harm to fish, shore	Harm to North Sea Harm to oil program Meshing of equipment
Unresolved conflicts	Alternatives to pollution control Actions for prolonged accident Degree of advance preparation	Role in accident Role in inspection and enforcement	Responses to government investigations Cost-effectiveness of preparations Liability limits	Coordinate performance of separate units Researched advice versus best guess	Ability to prevent accidents Oil versus fish Degree of future damages Northern drilling program	Separate information gathering International versus national Limited versus unlimited liability Use of chemicals
Lessons learned	Action Command worked Advance preparation necessary Enforce preparation and cooperation	Need for a priori roles, information Human and oil safety split New appreciation of pollution control More information on operators	Strong government response Greater attention to accident potential More emphasis on crew supervision and training	Integrate research results a priori Greater training, coordination More applied research More safety research	Damages nil owing to timing and location of accident Accidents are part of development More resources for accident prevention and management	Nations interested and responding News media relations important Central news media information releases Coordination necessary a priori Enforced company cooperation

oil slick. Before the Bravo incident, it was assumed that these two points could never have arisen; during the incident, however, it was obvious that research and development programs had not been pursued with sufficient vigor. Little or no information existed about performance of booms and skimmers under actual weather conditions in the open sea or about the damage to be expected from an oil slick over a period of time. In addition, the need for capping wells and drilling reliefs should have been foreseen and actively studied.

Most of the conflicts encountered were satisfactorily resolved; most centered on the pollution-control operation rather than well control. The basic conflicts were over chemical dispersants versus mechanical equipment in pollution control and the best methods of using mechanical equipment for this purpose. Differences also existed over potential damages from the slick.

Clearly, the Bravo blowout will cause major changes in the approach to pollution control, not only in Norway but probably in the entire North Sea area. A reappraisal of the principles and equipment to be used in future accidents is of major importance for all North Sea countries. Some problems that need to be clarified will now be mentioned.

Risk

Establishing the Action Group was designed to minimize the risk of mismanagement. In line with this approach, the Action Group reduced risk by ordering Phillips to cap the well and make available a relief rig simultaneously. However, the Action Group may well have taken a risk itself in foregoing the use of chemicals and allowing the oil slick to drift, given the lack of knowledge on the fate of oil in the sea. This risk was probably unjustified considering the potential damages to marine organisms at sea and to coastal communities in both Norway and Denmark.

Pollution Control

Norway specified mechanical equipment of rated capacity for pollution control, even though doubt existed about both the equipment and its performance. Thus, reliance was really on the self-cleansing capacity of the sea. This approach differs from that used for chronic oil discharges, where pollution-control equipment is demanded, even though the sea can more readily absorb this pollution.

Information

Full information on the alternatives available must be known before an accident actually occurs; otherwise there is no basis for adequate decision making during the crisis. However, here neither information on the effectiveness of the equipment for pollution containment under the expected operational conditions nor estimates of subsequent damages were available. Total reliance on the claims of equipment manufacturers is unacceptable. Information about chemicals and mechanical equipment also seem to be unavailable from UK sources.

Supervision

The degree of supervision on the operating companies appears not to be a factor of accident record or phase of operation. Since Phillips had had two previous production accidents in the North Sea [37] and since it was undergoing a well workover after loss of a monitor into the well at Bravo, greater government supervision would seem to have been warranted. Realistic sanctions, such as prescribed and enforced shutdown periods, are also important in enforcing safety standards.

Response

Bravo showed that Norway was not well prepared to handle a blowout, even though its response was quite reasonable. Prior to Bravo the Action Group did not exist, nor did an adequate well-control capability, and untested pollution-control equipment was regarded as adequate for use on the high seas.

Cooperation

Bravo showed that each North Sea country had its own individual strategy for combating emergencies; these were not always compatible. In addition, each country assessed the risk of blowouts and the resulting damages differently. The commitment of a country's pollution control equipment elsewhere leaves it vulnerable to an oil accident in its own sector: Denmark's commitment of its total pollution containment equipment and vessel left it unable to cope with a 40-ton spill in its own waters during the Bravo incident. A need exists for an effective, compatible, integrated response to oil accidents in the North Sea. For example, it would be valuable to have agreement on a level of compatible standby equipment that would be readily available for loan.

Company cooperation during the Bravo accident did not seem to meet the stipulations of the Clean Seas Committee, which was formed by the oil companies for mutual assistance during accidents. Nor are company responses similar in each North Sea country. An integrated network of compatible and dependable responses is important for both the oil companies and the countries of the North Sea.

In 1967 Norway established a code of safe practice for offshore drilling and was the first country to do so [38]. In 1977 Norway was the first country to suffer a major oil blowout in the North Sea. Given the widespread environmental interests in Norway, it is clear that even safer drilling procedures will evolve and be integrated into the offshore petroleum development program. Better oil-disaster management practices will also evolve and contribute to improved environmental safeguards, but it remains to be seen whether this evolution will be truly comprehensive and well integrated into an overall system.

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3 THE GAS BLOWOUT AT MAERSK EXPLORER PLATFORM, DANISH SECTOR

David W. Fischer

On October 14, 1977, a gas blowout occurred in the Vagn-1 exploratory well being drilled from the Maersk Explorer jackup rig. The gas blowing from this exploration well was ignited and began burning approximately 90 minutes after the well went out of control. The flow from the well consisted of gas with some water and large amounts of sand. Because no oil was associated with this blowout, no pollution-control measures were necessary. The well was located in the Danish sector of the North Sea 10 km from the West German sector, so that, if an oil slick had been involved, an international response would have been required.

The blowing gas burned for approximately 12 hours and extinguished itself just as a Norwegian fire-spray vessel arrived on site. It was decided to drill a relief well to kill the well and another jackup rig being towed nearby was hired and started to drill only 24 hours after the start of the blowout. The blowout stopped of its own accord 10 days after it started, just before the relief well reached the gas-producing formation. Although no oil pollution occurred and both the fire and the blowout extinguished themselves, the operation was more expensive than the earlier Bravo blowout [1].

PRINCIPLES ESTABLISHED BEFORE THE VAGN-1 BLOWOUT

In 1962 the Danish government granted a 50-year concession covering all onshore Denmark to the A.P. Möller Company. Later this concession was expanded to include the entire Danish sector of the North Sea. A.P. Möller, a Danish ship owner, had no previous experience with oil and gas operations. The terms governing his concession were very general and left considerable latitude in interpretation and operation. Möller formed the Danish Underground Consortium with three oil companies based in the USA – Gulf, Chevron, and Texaco – and with Royal Dutch Shell, to operate the lease. Although Gulf left the Consortium in 1975, to date over 50 wells have been drilled.

The terms of the concession were very lenient and very few governmental technical evaluations were required about such matters as type of rig, location of rig, or drilling operations. The only way the Danish government could regulate offshore drilling was by extending the safety regulations that applied to onshore Denmark to activities offshore, and it was on this basis that the government required more detailed operator information and issued approvals for well applications. The Danish Energy Agency is the body that regulates the drilling operations of the Danish Underground Consortium through these safety regulations. However, the regulator cannot deal directly with the drilling operator or influence the well drilling and control program directly. The regulator has a formal relation only with A.P. Möller, not with the oil companies or their operator Chevron, who does the actual exploration drilling. Since only basic raw geological and well information is required, evaluative information about such data is not normally provided to the government. In addition, evaluative and non-safety drilling information during the actual drilling is not normally provided. However, evaluations of drilling are available on an informal basis when a government representative visits an offshore rig or the operator's offices. Even so, safety remains generally in the hands of the operator on the basis of his knowledge of "good oil-field practice" and his own self-interest in not incurring needless expense and injury. The only other possibility the government has of obtaining more information is through a change in the concession agreement with A.P. Möller.

Oil-pollution regulations exist for the Danish sector of the North Sea, and these regulations would affect drilling operations if an oil blowout occurred [2]. Under the regulations the government can take the lead in pollution cleanup, and one assumes the government could require the operators to take whatever measures it considered necessary. In this sense the Danish posture would be quite similar to that of the Norwegians. However, the major difference between Norway and Denmark in combating oil slicks is that Denmark relies on a mixed pollution-control response, including mechanical collection and chemical dispersants, rather than solely on a mechanical one. In addition, A.P. Möller has no pollution-control equipment, but relies solely on the cooperation of offshore operators and the government, whereas Norway requires each operator to maintain pollution-control equipment capable of picking up 8,000 tons of oil per day.

ORGANIZATION AT THE VAGN-1 BLOWOUT

This section emphasizes organizational responses by both the operator and the government. Because the government does not have a direct regulatory relationship with the operator, Chevron, it did not play a direct role in the operator's blowout response. Figure 3.1 shows the organizational relations that existed in the Vagn-1 blowout. The only formal tie between government and operator was via Danbor, a separate company organized by Möller to interface with the government.

Figure 3.1 also indicates the main government actors involved in monitoring the blowout. An ad hoc coordinating body or Steering Committee was set up, consisting of the Ministry of Trade as leader, the Danish Energy Agency, the Danish Geological Survey, and the Environmental Protection Agency; the Environmental Protection Agency played a somewhat passive role in this Committee because no pollution was determined to exist. Had the blowout involved oil pollution, it is likely that the Environmental Protection Agency would have taken the lead role, and that the Navy would have coordinated the collection or dispersant effort.

The operator, by virtue of having sole responsibility for stopping the blowout, organized a major effort to do so. Chevron directed the entire well-control operation and

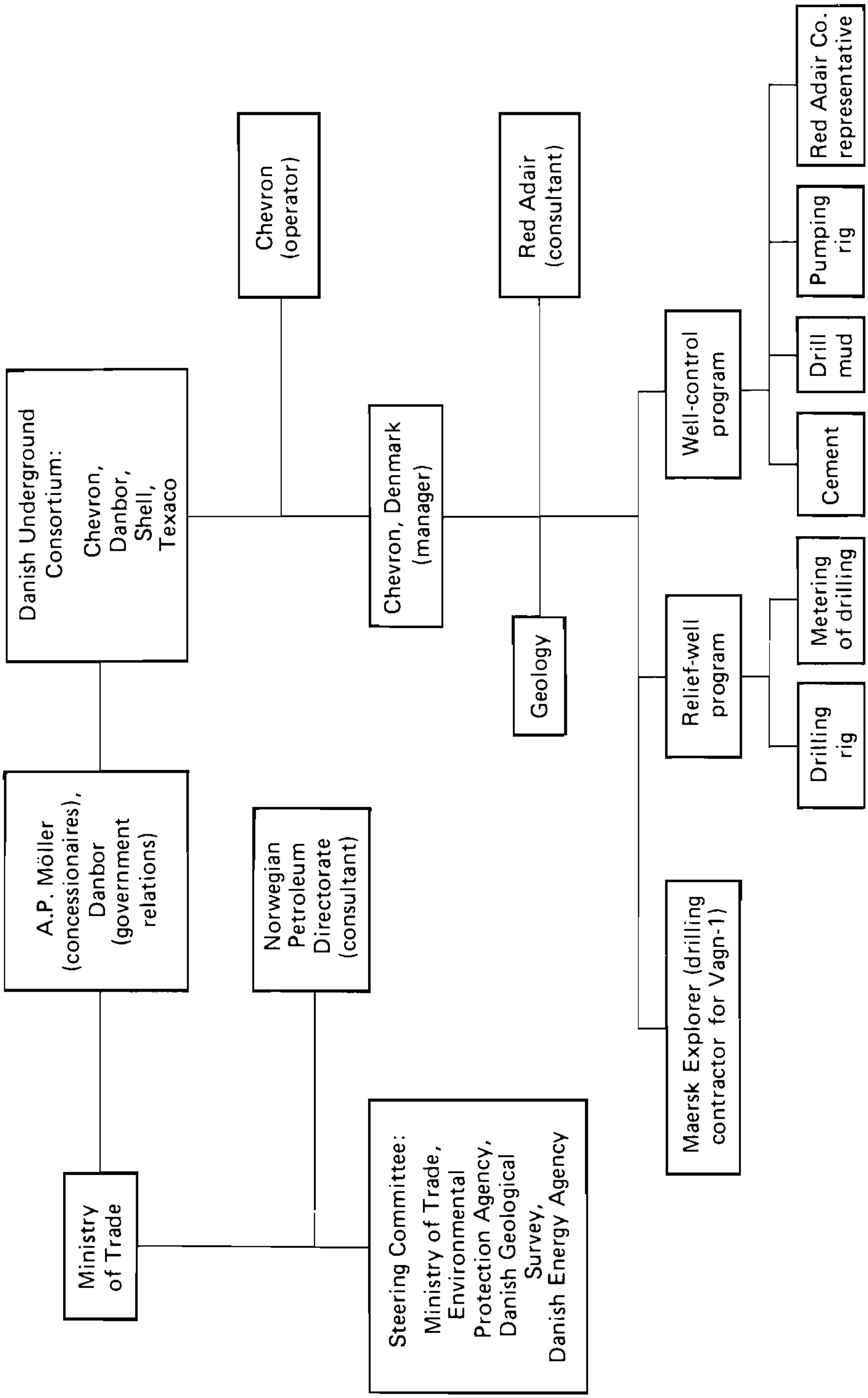

FIGURE 3.1 Organization to combat the Vagn-1 blowout.

made all major decisions in conjunction with its headquarters in San Francisco, USA. No Danish organizations had a major role, not even the Danish concessionaire, A.P. Möller.

Both the government and Chevron determined the need for outside expertise. The Danish Steering Committee requested the assistance of the Norwegian Petroleum Directorate, and Chevron requested the assistance of the Red Adair Company.

Finally, Figure 3.1 indicates some of the contractors involved in the well-control operation. Each operation listed in the figure was carried out by a separate contractor.

No pollution-control operations appear in this figure because an oil blowout did not occur. Oil-pollution operations would have necessitated a more complex and extensive set of government actors and actions.

DECISIONS MADE AT THE VAGN-1 BLOWOUT

Because the Vagn-1 blowout was the first to occur in Danish waters, several basic decisions had to be made, particularly on the government side. The Ministry of Trade, which has statutory authority for all operations offshore, formed the small Steering Committee described above. In its initial meeting further involvement by other government bodies was considered, as well as who should lead the group. It was finally decided that the Ministry of Trade would lead, since no pollution was involved. Other expertise within the government was on standby. The Norwegian Petroleum Directorate was called in to assist the Steering Committee in assessing the blowout and making recommendations.

After this organizational phase, the Committee requested information from Chevron via A.P. Möller about the present and planned future responses to the blowout. This initial request generated a discussion between A.P. Möller and the Committee about what kind of information and plans should be given to the Committee and also how much access the Committee should have to planning meetings, etc. The Ministry of Trade concluded that all information should be open for the Committee, and A.P. Möller finally agreed on this point.

Before receipt of the government's request for information, Chevron had already taken several actions of its own: notifying the government (Navy) approximately one hour after the blowout occurred; determining the need for a fire-fighting vessel and hiring one from Norway; deciding to drill a relief well, determining its optimum location, subcontracting the job, and preparing to drill; determining the need for information centers both offshore at the nearest rig and onshore at A.P. Möller; and deciding to engage the Red Adair Company as an external consultant and contracting for its help.

The Red Adair Company dispatched a representative to Vagn-1 and Chevron headquarters sent its own "troubleshooter" to the scene. Both the Adair representative and the Chevron expert agreed that drilling of the relief well should be continued. In addition, they suggested that Chevron should hire another rig to support a station for pumping drill mud rapidly into the relief well when it entered the gas zone.

When the Steering Committee received the information about Chevron's decisions and current activities, it required on safety grounds that the relief-well program and the rigs be approved. An application for these rigs was then submitted while the initial drilling activities were under way, and approval was given promptly on October 17, two days after drilling had begun. As part of its approval, the government required additional safety equipment to be used during the relief drilling.

In addition, the Steering Committee wanted a well-capping operation to be undertaken while the relief well was being drilled, if possible. Chevron rejected this plan on the advice of the Red Adair Company representative.

Just before the relief-well drilling began the blowout stopped ot its own accord on October 24. Then Chevron decided independently to kill its Vagn-1 well, developed a well-kill plan, and stopped drilling the relief well. The deck of the Maersk Explorer rig was cleared and the well killed. Then relief drilling was continued and mud and heavier materials were pumped into this relief well until pressure was stabilized and it could also be killed. Only after this event did Chevron request comments from the government's Steering Committee on its plans to clear the deck of the platform, kill the well, and stop drilling the relief well. These plans were developed by Chevron over 14 days and then given to the coordinating group with a request that they approve them the same day. Even though additional reporting and paperwork remained to be done, the major responses to the blowout ceased when the blowout itself ceased.

During Chevron's operations the Steering Committee had three major safety concerns: (1) a subsea or underground blowout might occur outside the well casing, thereby causing cratering and collapse of the rig as well as the geological structure itself; (2) the sand blown out of the well might accumulate on the deck of the rig and cause it to collapse; and (3) the overall safety and capability of the relief-well drilling operation.

The first consideration arose because of the pressure increase that accompanies a capping operation, and because the existing pressure could induce an additional blowout, followed by cratering and collapse. Cratering is a problem that has occurred recently elsewhere in offshore areas with high-pressure geological structures [3]. The second consideration was also serious because the accumulating weight of the sand on the rig was increasing stress on the legs of the jackup. The third consideration stemmed from possible disregard of normal safety precautions during the emergency relief procedure, which could have rendered the procedure ineffective, thus causing an additional blowout or loss of life, time, and equipment. These safety considerations partly underlay the government's requests for more information and their insistence on approving the responses to the blowout.

COMPARISON OF GOVERNMENT RESPONSES TO THE BRAVO AND VAGN-1 BLOWOUTS

This section compares the actions organized by the Norwegian and Danish governments in response to the blowouts that occurred in their offshore sectors of the North Sea. Figures 3.2 and 3.3 summarize the basic actions taken by the Norwegian Action Group and the Danish Steering Committee. There are two significant differences in these national responses: the Norwegian response assumed the more authoritative role compared to the Danish coordinating role, and was centered around a pollution-control effort that was not necessary in the Danish case.

Under the terms of the exploration licenses granted for the Norwegian shelf, the government reserved the right to assume authority for blowout responses if it deemed the licensee to be acting inadequately [4]. In such a case all actions taken by the Norwegian Action Group are at the expense of the licensee. In addition, the Norwegian Petroleum

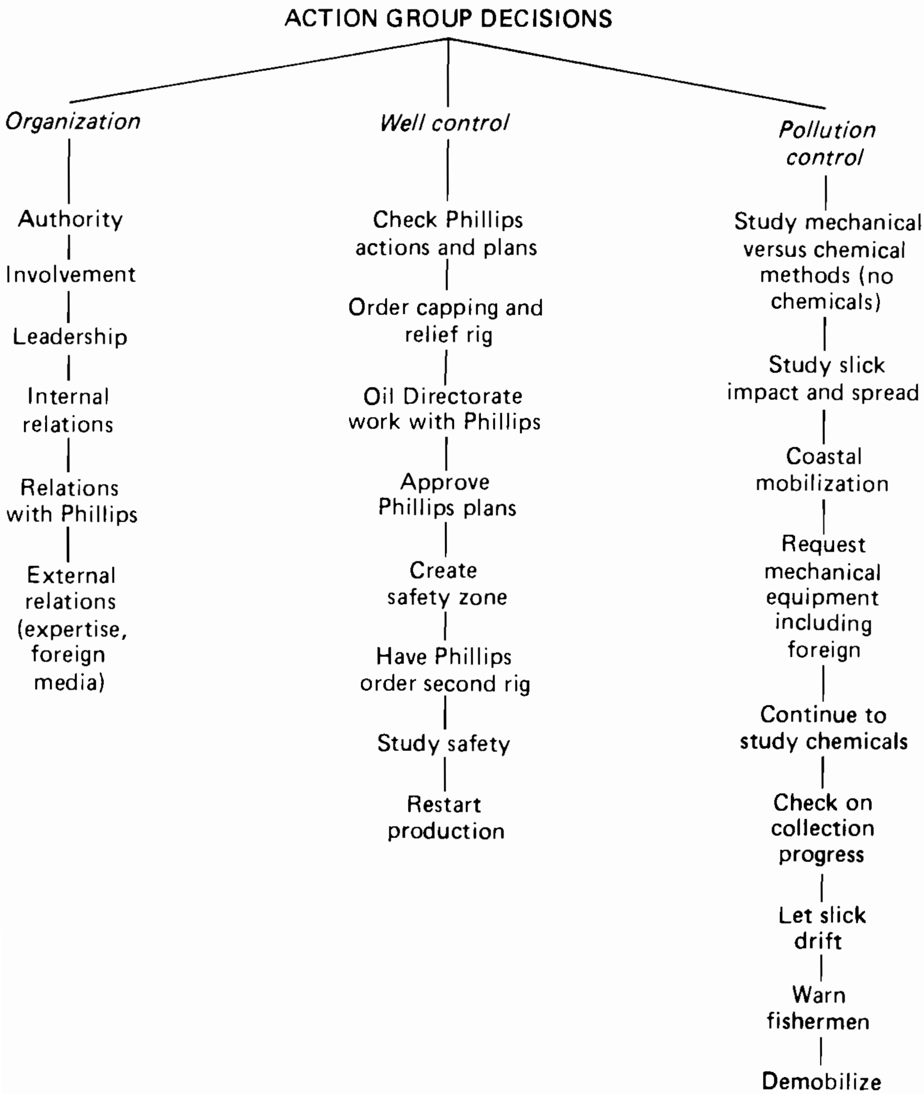

FIGURE 3.2 Government actions at the Bravo blowout, Norwegian sector.

Directorate deals directly with each oil operator on an individual basis and must approve its interpretations of the drilling program and subsequent modifications. Under the terms of exploration granted by the Danish government this right of direct supervision was not reserved to the government. Therefore, the Danish Energy Agency, which has day-to-day responsibility for offshore regulation, must rely on the operator's sense of safe oil-field practice. Thus the Danes have a more passive response to offshore blowouts than the Norwegians.

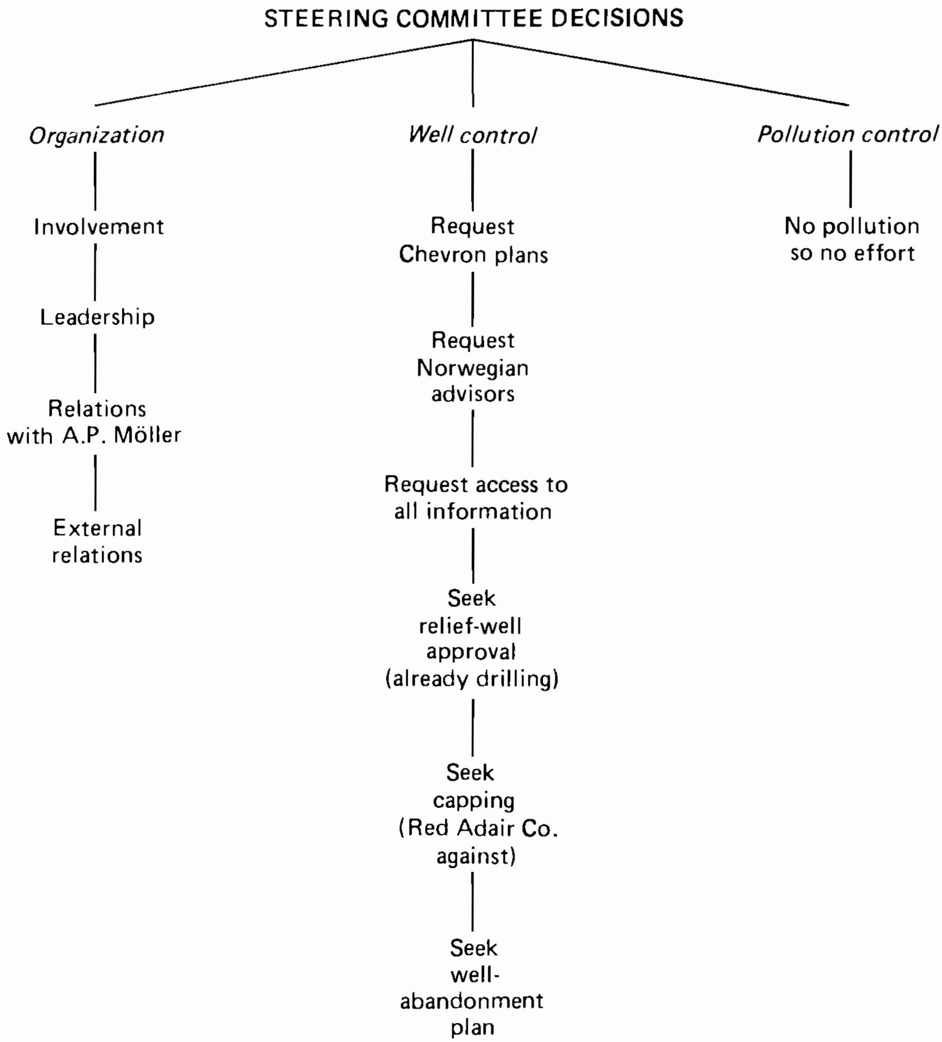

FIGURE 3.3 Government actions at the Maersk blowout, Danish sector.

Table 3.1 compares the Norwegian and Danish responses to their blowouts. The Danes were not in a position to assume a role of authority over Chevron because of the general and vague terms of the offshore lease and the questions still remaining on the offshore applicability of onshore safety regulations. Therefore, the Danish Steering Committee took a passive role; the operator made all the important decisions on well control without advising the Committee until after the work was under way. Information requested was initially denied and later only partly furnished; the Steering Committee was unable to

TABLE 3.1 Comparison of regulator–operator relationships for the North Sea blowouts, 1977.

Norway: Bravo blowout	Denmark: Maersk blowout
Action Group in command role	Steering Committee in passive role
Action Group in direct contact with Phillips	Steering Committee not in direct contact with Chevron
Action Group advised on plans before implementation	Steering Committee advised after the event
Operator and Action Group made joint decisions	Operator made all important decisions
Operator shared information on request	Operator did not share information on request
Action Group and Petroleum Directorate evaluated data	Steering Committee did not see data
Government investigated	Government did not opt for a special investigation

see the data on which Chevron's decisions were based. All contact with Chevron was made indirectly through A.P. Möller via Danbor.

After the emergency Denmark elected to investigate the Maersk blowout accident by the sort of maritime inquiry that is normally held for a shipwreck, to be followed by a report from the Steering Committee to parliament. In contrast, the Norwegian government appointed an independent fact-finding commission to determine the causes of the blowout, required a formal public report from its Action Group on its relations with Phillips as well as on the entire blowout response, and mandated a formal public report to the Storting, its parliament. Sanctions and fines were levied on Phillips personnel and others deemed responsible. Offshore safety and operating conditions were strengthened by the Petroleum Directorate. A major research program on offshore safety measures and contingency planning was begun and funded at a high level. Finally, the Norwegian government made the Action Group into a permanent body to deal with offshore emergencies.

Denmark's response was to extend the applicability of all onshore safety regulations to offshore activities and to take an initial step toward establishing a permanent body along the lines of the Norwegian Action Group. The terms of the offshore concession agreement with A.P. Möller are a major constraint against Denmark adopting a stronger line. However, some demands are being made by politicians for changes in this leasing arrangement.

EVALUATION OF SOME ISSUES RAISED BY THE BRAVO AND VAGN-1 BLOWOUTS

The Bravo and Maersk blowouts have raised issues about human error, regulator–operator relations and roles, substitute decision-making groups, expertise available from other countries, the degree of cooperation and response desirable between operators in different countries, the vulnerability to one's own interests when aiding others, and determining an adequate response.

Human error was the basic cause of both the Bravo and Maersk blowouts. The Norwegian Commission of Inquiry reported [5] that the "underlying cause of the accident was that the organizational and administrative systems were on this occasion inadequate to assure safe operations." Before the Bravo blowout the BOP was in two separate parts on the deck; it was not hanging in place over the wellhead. Nevertheless, the well was opened in spite of signs that it was already unstable. Neither the drilling supervisor nor the drilling engineer were available on deck to check these operations, even though they knew the well was unstable. Finally, the qualifications of the drillers were inadequate because their theoretical knowledge and experience had been gained solely in land-based operations [5]. In the Maersk blowout human error was also placed at the heart of the accident. It was known that the gas zones were shallow, and that there was no BOP available; also, the pipe was taken off too soon, the signs of well instability were ignored, and the necessary inspections of equipment had not been made [5].

Thus, there appears to have been little thought given to a blowout in either case, since both blowouts were seen as preventable by government representatives. While human error will always exist, it does seem that greater care was called for during the well workover at Bravo and at the exploration well on Maersk than was exercised. Ensuring just how to prevent human error by circumscribing human behavior in a mode conducive to greater safety will always be a subject of concern in complex technologies operating in hazardous environments. However, the governments and the societies they represent have every right to ensure that greater attention be given to the human dimension, and especially to preparedness to meet emergencies and contributing events. While greater priority is being placed on the safety of technological systems, this should be matched by concern for the human interface with these systems. Although there is frequent transfer of personnel from one region to another, operators cannot assume that experiences gained in one region are transferred to the others. Training, orientation, supervision, and inspection remain important if blowouts are to be prevented, regardless of the number of BOPs used.

Relations between the regulator and the operator are defined both formally and informally. However, the formal setting for these relations provides the basis for the bargaining done at the informal level. In the Norwegian case, the authority of the Norwegian Petroleum Directorate had been established by Royal Decree to grant concessions to private oil companies. Through this authority the Directorate worked directly with oil companies in defining the conditions of oil operations both before and during such operations [6]. Owing to this standing authority, Phillips was prepared to play a subordinate role to the ad hoc Action Group organized by the Norwegian government in response to the Bravo blowout. In Denmark the Danish Energy Agency was constrained by the earlier concession agreement arranged between A.P. Möller and the government.

Substitute decision-making bodies were prominent in the responses to the Bravo blowout. Phillips requested the assistance of the Red Adair Company, which took over the well-control program, while Norway formed the ad hoc Action Group to supervise Phillips' well- and pollution-control efforts. Both Red Adair and the Action Group supplanted the normal operating relations of Phillips and the Norwegian Petroleum Directorate. Questions of authority, responsibility, liability, knowledge, and impact on future endeavors and relations are all at issue when substitute decision-makers are used. These issues had not been fully studied before the Bravo incident. In Denmark, Chevron retained control of all well-control operations and the Danish Steering Committee had no decision-making role. Thus, this issue was not raised in the course of the Maersk blowout.

Using experts from other countries raises issues of accountability of action, transferability of knowledge, and coordination of effort. In a foreign place the results of advice given by a foreign expert do not greatly affect him, since he leaves at the end of the emergency. The nationals must cope with and adjust to whatever results have evolved from his advice. The basis of such advice is expertise, but such knowledge may not fit the local conditions or be readily coordinated and assimilated. Thus, the overall management effort can be biased when foreign experts are used.

In the Maersk incident the Danish blowout was entirely in the hands of a foreign oil company that took direction from its US headquarters. At Bravo the authoritative role taken by the Action Group was partly based on the issue of foreign domination of national concerns. However, at the operational level, well-control expertise was imported in both cases and little effort was made to allow national experts to participate in these operations, either in their planning or in their conduct. Finally, the questions of knowledge and coordination were raised in the pollution-control operation at Bravo. The performance characteristics and handling properties of foreign booms and skimmers were unknown, so that no recourse to such equipment was made, even though it may have been superior. Also, foreign crews were underused, even though Danish and Swedish, and also British Petroleum pollution-control vessels and crew were on the scene. Similarly, criticism by national fishing interests may have discouraged the use of available low-toxicity dispersants from the UK, regardless of their effectiveness. All of these examples raise the issue of the role of foreign expertise in an emergency. Clearly, it is important to plan to use foreign expertise to contribute to an effective management strategy and to minimize the problems stemming from such advice or use.

Failure of the oil companies to cooperate during the Bravo blowout, and the different oil-company responses planned for different countries raises another issue. For example, A.P. Möller relies exclusively on oil companies to combat pollution and control blowouts in the Danish sector. It has no equipment of its own to cope with these problems. In Norway each company acts independently with its own equipment and with little sharing among them, which forced Phillips to seek equipment from the USA. On the other hand, a committee has been formed in the UK to share pollution-control equipment. In sum, there is a need for an integrated international response system involving all participants, including oil companies and national governments.

Cooperation in responding to an oil blowout means that a company or country must have additional capacity available for its own emergencies. For example, Denmark's commitment to Bravo of its main pollution-containment vessel and equipment left it unable to cope with a simultaneous 40-ton oil spill in its own waters. Also, Norway released its only large-capacity fire-fighting vessel to Denmark for Maersk, thereby leaving itself vulnerable. Other redeployments included a British fire-fighting vessel going to Ekofisk from the UK Forties Field, and the maintenance of another fireship had to be postponed so that it could go to the Forties Field if necessary. Clearly, the cost of standby equipment is high and must be balanced against the probability of simultaneous blowouts or tanker spills. No integrated company–government responses on an international level had been developed before the blowouts of 1977, so that efforts to achieve this end were necessary, although much still remains to be done.

The final issue raised by these blowouts concerns the question: what is an adequate response system to a North Sea blowout? The Norwegian and Danish experiences show there is a possibility of overreaction; this was particularly so in Norway, where fishery-oriented political interests are strong. In Norway, drilling north of latitude 62° N was again postponed and many special operational and research programs implemented [7]. The direct cost of these programs exceeds US $100 million and the indirect costs of displaced priorities and other activities remain to be calculated. Many of the items now being planned were, of course, overdue and necessary, such as UK–Norwegian cooperative agreements on mutual assistance during blowouts or tanker spills. Other items, such as duplicating drilling supervision on platforms or charting all national emergency resources, may be excessive.

At present Norway has a permanent Action Command Group with staff that is capable of integrating all emergency plans and responses to unplanned events. This unit must organize itself and establish workable relations with the myriad bodies regulating petroleum development offshore. Other kinds of emergencies must be foreseen as well. Both Norway and Denmark have begun to create just such an infrastructure. To create a well-integrated and comprehensive disaster-management system will take skill, care, and judicious allocation of priorities and resources, but both countries have the means to do so.

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4 ORGANIZATIONAL ISSUES AT BRAVO AND THREE MILE ISLAND: A COMPARISON*

David W. Fischer

From approximately 22.00 on April 22, 1977, when the Bravo well went out of control until well control was regained at 11.00 on April 30 between 12,700 and 22,500 tons of oil escaped into the sea. This oil blowout, the first major accident in the North Sea involving a producing offshore platform, captured worldwide attention and signaled to the North Sea oil industry and governments that oil blowouts can occur even though in-depth prevention and safety requirements exist. Before this accident, blowouts were viewed as "impossible" in the North Sea. The Royal Norwegian Commission of Inquiry, created to investigate this accident, reported that "the underlying cause of the accident was that the organizational and administrative systems were on this occasion inadequate to assure safe operations," that the "accident to a large degree was due to human errors," and that, while "certain technical weaknesses were present," they were only of "peripheral significance for the course of events" [1].

Almost two years later, at approximately 04.00 on March 28, 1979, a series of events at the Three Mile Island (TMI) nuclear plant in Middletown, Pennsylvania culminated in an accident with a partial core meltdown. From this time until the initial danger subsided on April 2 an unspecified but probably low amount of radiation was released into the environment. This nuclear accident was the first major accident in the USA, and it too captured worldwide attention and signaled to the nuclear industry and governments that nuclear accidents were a reality to be reckoned with, even though in-depth prevention and safety requirements exist. Before this time such accidents were also viewed as "impossible." The US President's Commission [2] to investigate this accident concludes that "fundamental changes will be necessary in the organization, procedures, and practices – and above all – in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions we investigated are typical, of the nuclear industry."

In view of the striking similarity in the key conclusions stemming from the investigations of these two accidents, it is reasonable to compare some of the organizational and administrative issues surrounding them, particularly since both have resulted in slowing down the production of new energy in an energy-scarce world. The purpose of this chapter – added to the book after the original manuscript had been completed but before it had gone to press – is to make such a comparison.

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It is perhaps surprising that each of these accidents has triggered public controversy and caused temporary moratoria on further development, since neither accident caused significant offsite damage. The oil slick at Bravo that escaped being contained did very little damage to marine life, and no oil reached the Norwegian or Danish shores. The radiation releases at Three Mile Island were largely contained, and the overall health effects have been found to be minimal. There was no loss of human life in either accident.

Nevertheless a variety of issues underlay both these moratoria. To investigate these sources of concern is important, but this chapter will confine its attention to the organizational and human responses to the two accidents. Nor will it outline the sequence of events in the accidents or discuss their significance. Certain human and technical features are comparable, and interested readers are urged to compare them, but a total comparison is beyond the scope of this chapter. Table 5.1 gives an overview comparison, but readers interested in more detail should consult other books and papers (for example: for the Bravo accident, this book and the report of the Commission of Inquiry [1], for the TMI accident, Lathrop [3] -- a companion volume to this one – and the report of the President's Commission [2]). A bibliography of some original written testimonies and other general references of interest is given at the end of this chapter.

THE ACTORS

Given an inherent awareness of accident probability, why were these two accidents seemingly unexpected and the organization and administrative practices surrounding their management created ad hoc? Such a question can be studied partially by looking at the actors expected to respond to accidents. Their ideological foundation for safety and accident management and for its communication and linkage to other social actors appears to be an important determinant of the adequacy of organized responses to large-scale accidents.

Any technology has a protective core of organizations or actors linked together by a common ideology or set of oversimplifications of shared knowledge and interests that supports it, since the technological expertise and the ideology it requires give power to organized technical experts in private and public bureaucracies. And energy technology is no exception to the rule. Such influence is communicated to other actors, whether rival, beneficiary, or sufferer, via information used to foster public opinion to achieve the ends desired by the technocrats and others sharing the same values [4]. For example, while setting a safety standard directly involves industry designing, manufacturing, supplying, using, and servicing the technology, as well as the regulator, other actors include unions, politicians, local governments, residents, consumers, rival technologists, other government agencies, research experts, etc. Such a broad array of actors drawn into setting a safety standard can generate conflict because of differing perspectives and ideologies [5].

This proposition has as its core the concept of actors or social groupings representing various organizations involved, or wanting to be involved, in the responses to safety and accident management. As the responses to the accidents at Bravo and TMI showed, new organizations can be created instantly (as at Bravo) and new roles can be created by and for existing organizations (as at TMI). Major actor groupings that are useful in examining and comparing accident-management roles and linkages at Bravo and

TABLE 5.1 The Bravo and TMI accidents.

Item	Bravo	TMI
Location	Norwegian sector of North Sea	Middletown, Pennsylvania, USA
Technology	Offshore oil production platform	Nuclear power plant
Accident	Oil blowout, first in North Sea	Core overheat, first in USA
Timing and extent	Late evening, eight days	Early morning, six days
Indirect cause	Maintenance program	Maintenance program
Early warning	Mud leaking from valve	Water leaking from polisher valve
Initiating event	Stuck-open downhole safety valve	Stuck-open pilot-operated relief valve
Contributing events	Not ready to install backup valve and installed upside down	Not able to see to close backup valve and shut down cooling pump
Onduty crew	Did not act on warnings. Did not share information between shifts. No formal engineering education. Lacked experience of offshore events	Did not act on warnings. Did not share information between shifts. No formal engineering education. Lacked experience with events
Supervisors	Lack of theoretical knowledge. Onsite but absent. Lacked experience with events	Lack of theoretical knowledge. Offsite. Lacked experience with events
Investigation	Royal Commission of Inquiry on Bravo	President's Commission on TMI
Basic cause	Weak organizational/administrative systems	Weak organization, procedures, practices
Prevention	Preventable	Preventable
Safety program	Existed but no details of inspections. No plans for stopping uncontrolled well	Existed but no details of inspections. No plans for stopping core melt
Accident management	Hindered by responses	Hindered by design and responses
Maintenance program	Not detailed or approved. Changed at will, poorly organized	Not detailed but approved. Poorly organized
Communications	Internal communication poor	Internal communication poor
Damages	Nil offsite. Lacked offsite monitoring and containment equipment	Nil offsite. Lacked offsite monitoring equipment. Extensive onsite
Liability	Operators created pooled fund. Public assumed company liable. North Sea states agreed to limit liability. Norway recognized only limited liability	Operators sought Price–Anderson Act to limit liability. Public assumed government liable
Political impact	Temporary moratorium on drilling north of 62° N	Temporary moratorium on new plants

TMI include: the company(s) owning, operating, and servicing the technology; the government agency(s) regulating the technology; the response agency(s) with responsibilities for managing emergency situations/accidents (this agency can also be part of a regulatory agency); the inside experts from government agencies, research institutes, companies, and universities; the heterogeneous social groups impacted, that is, potentially benefiting or suffering from the technology and any associated accidents; and the exogenous and unorganized influential groups that an accident affects, such as politicians, outside experts, and news-media representatives.

While each of these actor groupings has a different ideology, including goals, incentives, information, perceptions, and alternatives, the accident is the basis for their being bound together in some form of combined and linked management response. Their inconsistencies can be used, set aside, ignored, or canceled in order to meet the commonly perceived threat.

No direct a priori organizational forms normally exist to integrate all of these actor groups; rather the accident itself is the integrating factor. Choices of organizational form and function have tended to evolve during the course of accidents, as occurred at Bravo and TMI. The actual responses were ad hoc, based on experiences during the accident, rather than on normatively derived organizations and administrative practices from a priori analyses. This ad hoc approach has the advantage of allowing access by certain impactees and exogenous actors into the accident-management systems, but it can lead to interference and incorrect interpretations both within the management system itself and for the public at large. Thus, a planned accident-management system should include seemingly external, but influential and involved, actor groups.

If a large scale, politically important accident can involve such actor groups, the question is: who is involved and in what ways? The links among these actor groups for the purposes of onsite accident control, mitigating the offsite consequences, and the giving and acting on information about the accident are also of concern.

THE ACTOR AND ORGANIZATIONAL RESPONSES AT BRAVO AND TMI

Table 5.2 is the cornerstone of the comparisons that this chapter discusses; it lists six types of actors and has been designed to be self-explanatory, so that only amplification of selected issues will be discussed in the text.

For the accident response organizations the significant differences between Bravo and TMI lie in their manner of creation and the degrees of authority and centralization. At Bravo an immediate ad hoc decision was made by the Minister for the Environment to place all major regulatory and supportive actors into one Action Command under a single leader. While this response existed earlier in outline form, it had never been implemented and was done so by oral authority within hours after notification of the accident. All onsite and offsite public responses were placed under this single technocratic actor, and the Action Command was a direct representative of the central government, so that no politicians had to participate directly in its decisions. The Action Command carried out its functions through the normal regulators and left the primary responsibility for managing the onsite and offsite consequences with the operator. In addition, all official statements were released to the news media through this one body, which eliminated the possibilities of conflicting and speculative information from the operator or elsewhere within the government. Finally, the Action Command had a priori authority to take over the management of the accident from the operator if it was deemed necessary in the public interest.

At TMI this actor type was created ad hoc in the midst of managing the accident by the two top politicians concerned, one of whom directed the key offsite responses personally. The organizational form was decentralized into three separate headquarters using political and technocratic actors whose responsibilities matched their normal jurisdictional boundaries. An understanding of the accident and communications among these sets of actors thus became crucial, especially with increasing distance from the site of the accident. Oral authority was also used by these politicians in the creation of this form of

TABLE 5.2 Comparison of actor types for the Bravo and TMI accident responses.

Actor type	Bravo	TMI
Accident response organization(s)	Organized at beginning of accident	Organized during the accident
	Direct authority to take over accident if necessary	Indirect authority to take over accident
	One centralized body for onsite/offsite responses including normal regulators as part	Actors merged into three groups with split responses between onsite/offsite
	Worked through normal regulators who implemented decisions	Finally based on normal regulator
	Centralized source for information	Separate sources for information
	Political role in background	Political role required
Normal regulator(s)	Contingency planning had begun	Contingency planning had not fore-seen accident
	Reliance on operator self-interest	Same as for Bravo
	Preaccident regulatory functions split by speciality	Preaccident regulatory functions centralized
	Local authority of regulator recognized	Regulator has no local offsite authority
	No a priori accident roles, alternatives developed	Same as for Brave
	Adopted passive role in accident	Adopted ad hoc active role in accident
	Contained political and public anxieties	Created political and public anxieties
	Good internal communications	Poor internal communications
	No onsite regulators	Moving to onsite regulators
Operator	Unlimited liability plus obligation to reimburse offsite costs	Limits to liability
	Small petroleum company	Small utility company
	Reason to expect accident	Unexpected accident
	Primary responsibility for accident responses	Same as for Bravo
	Knew regulator would supplement response	No a priori regulator response role
	No a priori alternatives	Same as for Bravo
	Used ad hoc external experts	Same as for Bravo
	Other operators gave no support although in plan	Other operators aided in accident on request
	Relied on own wishes for offsite responses (chemicals)	Relied on NRC directives/advice
	Met with government for public information	Met news media alone on request but later not at all
Experts	External foreign companies have key accident control role	Manufacturers have key advisory role
	No a priori plans for scientific and foreign support	A priori roles transferred to TMI
	Plane and computer used in plotting slick	Same as Bravo (for cloud)
	Scientific agreement on management	Scientific conflict on management
	Scientists volunteered	Scientists requested
Impactees	Marine life	Area residents
	Affect aesthetics	Affect health, life

TABLE 5.2 (*continued*).

Actor type	Bravo	TMI
	Areas of impact unknown	Areas of impact known
	No a priori roles for communities	A priori for counties within 5 miles
	Rely on news media for information	Same as for Bravo
Exogenous	Site visit by Prime Minister	Site visits by President, Governor
	No active political role	Significant active political role
	No a priori roles for news media	Same as for Bravo
	News information harmonized and centralized	News information conflicting and separated
	Used both officials and professional news media experts	Used officials
	Outside experts exploited accident	Same as for Bravo
	No a priori foreign cooperative/roles	Same as for Bravo
	No ongoing international forum	Have IAEA

response. Information was given to the news media jointly by the Governor of Pennsylvania and a designated representative of the Nuclear Regulatory Commission (NRC), both of whom were directing the key onsite and offsite accident-management activities. The Pennsylvania Emergency Management Agency (PEMA), which was given greater authority during the accident, became separated from the information flow from the Governor's Office during the later stages of the accident.

Accident management was split among different actors because of the unfamiliarity with nuclear accidents, the slow recognition of the nature of the accident, conflicting information and recommendations from the NRC, the rising interest and conflicting information being presented in the news media, the potential for public misinformation and panic, and the potential political impacts on government and the future use of nuclear power. Three separate accident-management and information centers were established ad hoc during the course of the accident. This arrangement was only possible because of action by the State Governor and the President of the USA, who acted to limit the sources of information and to consolidate the supporting agencies. These centers were: the onsite accident center at the TMI plant, which was supplemented by NRC headquarters staff, where one man became the source of all technical and onsite information; the offsite accident-management center in the State Governor's Office, which coordinated all state and federal responses and was the source of information on evacuation and other protective measures; and the President's Office, which coordinated the federal agency responses for emergency relief and gave out information on this effort.

The direct responsibility for onsite management of the nuclear accident became a moot point as events progressed, because of the increasing involvement of the NRC in cooling down the reactor. No a priori authority existed for the NRC to take over the management of the plant from the NRC licensee-operator. In addition, the operator was requested not to release information to the news media and was not present at press briefings.

The normal regulators at Bravo and TMI played different roles in managing these accidents. The crucial differences are that the NRC headquarters first took an ad hoc active role in the accident at a distance, and later onsite at TMI when asked to do so by the President of the USA. Accident information that got to Washington, DC from the site generated considerable concern and some hasty recommendations, which, in turn, prompted misinformed advice to offsite managers and speculative statements to the news media. The NRC role at the site contributed to its onsite management, while the NRC in Washington, DC created needless anxieties among offsite managers and the general public. The details of the information flow between the NRC Regional and Washington, DC Offices are not clear from accident accounts. No a priori scientific knowledge seemed to guide the NRC in responding to this multifaceted accident or in understanding the nature of the hydrogen bubble. This combined lack of scientific knowledge and appropriate responses was a shortcoming and should have acted as a brake on hasty and speculative statements to the accident managers and the news media [2].

During the Bravo accident the onsite regulator, the Oil Directorate, played only the passive role of checking and assessing the operator's prospective plans for controling the accident. This regulator then advised the Action Command on the quality of the plans presented. The offsite regulator, the Pollution Control Authority, played a supplementary role in that it directed the operator to use mechanical pollution-control devices and aided Phillips in finding and using them.

The operators at Bravo and TMI each had primary responsibility for preventing and responding to accidents. Each responded similarly by protecting their employees and physical plant, by calling in industrial experts to supplement their efforts, and by notifying and cooperating with government regulators and accident managers. Also, each operator cooperated with the wishes of its government's accident-response actor with regard to the news media. Neither operator relied on previously developed assessments of alternatives in responding to the set of events confronting him, including preventing escalation of the accident level as well as responding to it. Accident management was not a priority for these two operators.

Both of these accidents should have been expected. However, in both cases the supervisory and operational staffs did not respond correctly while the accident was still preventable. Once the accident had occurred, the experts from elsewhere in the industry occupied key roles in bringing it under control.

At Bravo Phillips Petroleum had the primary responsibility for preventing and responding to an accident. This responsibility existed, even though the 1977 accident occurred during a time of transition from few preparations to moving toward an adequate posture for mobilizing to meet this responsibility. Thus, it would seem that the government regulators should have had some role or means of supplementing the operator's existing responses before the operator was fully capable of responding to an accident in the required manner. The reason given for not having such supplementary postures a priori was the belief that no accident would happen in the interim, the fact that the requirements had already been imposed on the operators, and concern for diluting the operator's degree of responsibility.

Other oil companies operating in the Norwegian sector of the North Sea did not come to the aid of Phillips in this accident. Although a cooperative plan existed among the oil companies, it was not followed. On the other hand, at least one offer from the UK sector was received and accepted. Apparently, a fear of future government responses toward oil development inhibited the oil companies responding to Phillips' plight, as well as the government's decision to ignore the use of chemicals, which was the only alternative the oil companies could immediately use in a joint response. Requirements now exist for intercompany responses to accidents based on the use of mechanical methods of pollution control.

At TMI the company itself had the primary responsibility for responding to the accident, as long as the status of the accident and its consequences were contained within the perimeter of the plant site. The plant staff summoned technical engineers from its parent company for operational efforts to contain the accident. In addition, the plant supervisor brought in representatives from Babcock and Wilcox, the designers and constructors of the reactor cooling systems, their control, and their instrumentation. Finally, at a later stage in the accident, aid was requested from the nuclear industry, which responded by creating an ad hoc advisory group consisting of representatives from other private nuclear plants. Because the consequences of the accident went beyond the plant itself, into the adjacent environment and beyond, the plant supervisor also notified PEMA, the regional office of the NRC, the local county, the parent company, the Brookhaven National Laboratory, the Pennsylvania Bureau of Radiation Protection, and the State Police. The supervisor also dispatched onsite and offsite radiation monitoring teams.

The experts used in responding to each of these accidents had similar tasks: to control the accident, to track and predict the radiation cloud/oil slick, and to help control the consequences. At Bravo no scientific roles for experts had been developed a priori, and so they were initiated by the scientists, while at TMI scientific roles developed for government nuclear facilities were transferred on request to the TMI situation. However, at Bravo scientists generally agreed on the predictions and state of the oil slick, while at TMI considerable disagreement existed over the nature and consequences of the accident and its radioactive emissions. Industrial experts were directly involved in controlling the accident itself, while government experts concentrated on the bubble and offsite impacts. A priori and integrated roles had not been developed for these actors.

The total reliance on one foreign expert with no local experience for the key role of regaining control at Bravo might appear as a weakness in an effective accident-management system. While the Red Adair Company has a worldwide reputation within oil-company circles, the vast majority of its experience rests with killing blowouts on land where access to and space for amassing equipment to kill the blowing well is always available. However, the design, height, and complexity of the large North Sea offshore platform hinders the use of capping procedures. Therefore, a possibility of prolonged offshore accidents exists, and localized experience in developing internal, integrated expertise has been suggested.

The impactees for these two accidents were quite different: Bravo affected marine life and potentially threatened coastal communities, whereas TMI potentially threatened the lives and health of residents in the area. However, in each of these accidents no major adverse impacts occurred to workers, residents, or the biological environment. In fact, one could conclude that the offsite damages were virtually nil in both cases. A priori roles were underdeveloped for potentially affected residents, and the information links for most impactees were the news media.

At both Bravo and TMI exogenous actors became increasingly involved during the course of the accidents. Politicians were essential actors in both cases. However, the immediate appointment and confirmation of a politically delegated authority at Bravo ensured the role of the Action Command as *the* accident manager. At TMI, two politicians had to intervene during the accident to bring order out of the seeming chaos created by conflicting information and recommendations. Site visits were made by politicians in both countries.

The news media played a significant part in relaying information to area residents, national citizens, and the world at large. News reporters were from local, national, and foreign sources, all serving different interests and making different demands on the information machinery. No public information roles and facilities had been developed before these accidents occurred. Consequently, both information sources and their quality contributed to the confusion, particularly at TMI. News representatives assigned to cover these two accidents did not have enough technical knowledge to judge the content of the information or to develop useful questions to be put to accident managers.

Outside experts used both of these accidents as vehicles to convey their views to the news media on the technologies and their broader public impacts. Such views were used for a variety of reasons, even to convey a lack of confidence in the accident managers' information. These reported views contributed to public alarm during the accidents and to the decisions for temporary moratoria made by politicians after them.

Foreign observers were present at each of these accidents and their demands for information were high because of the actual and perceived consequences in their own countries. At Bravo foreign observers were present throughout the accident and observed the conduct of the Action Command. In addition, foreign observers were present in aircraft tracking the direction and extent of the oil slick. Finally, foreign groups played essential roles in the pollution-control effort to contain and capture the oil slick. The Bravo accident prompted a closer cooperation between Norway and the UK in planning integrated accident-management responses. At TMI foreign observers were present at the NRC office at Washington, DC during and after the accident, and later at the plant itself. In addition, international agencies have studied the implications of both of these accidents.

Figures 5.1 and 5.2 group the six actor types into the preaccident management system, the ad hoc organized responses, and the unorganized accident responses. These three sets of accident responses existed at both Bravo and TMI and could, therefore, be expected to exist in various forms in future major accidents. Together, these three sets of responses constituted the overall accident-management system.

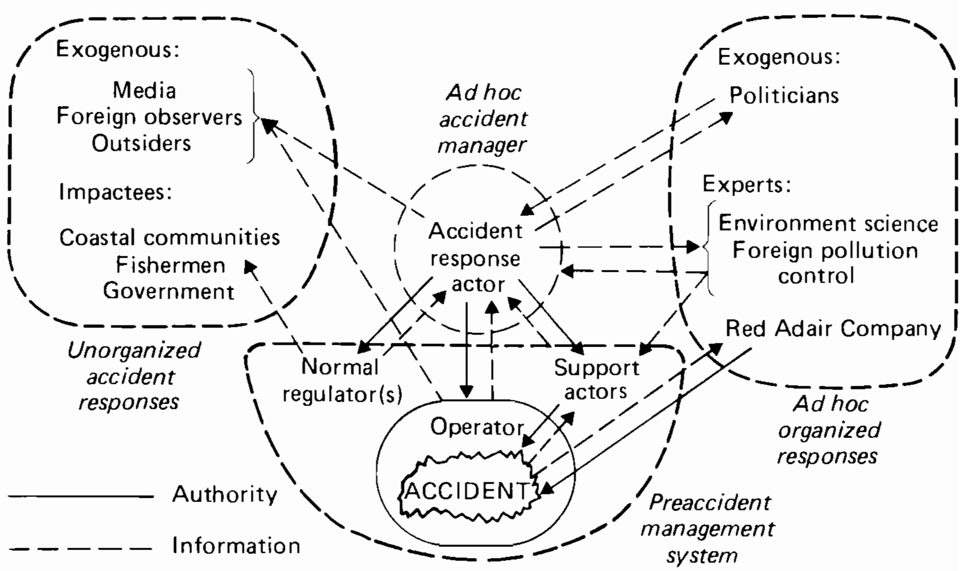

FIGURE 5.1 Principal actors and linkages forming the accident-management system at Bravo.

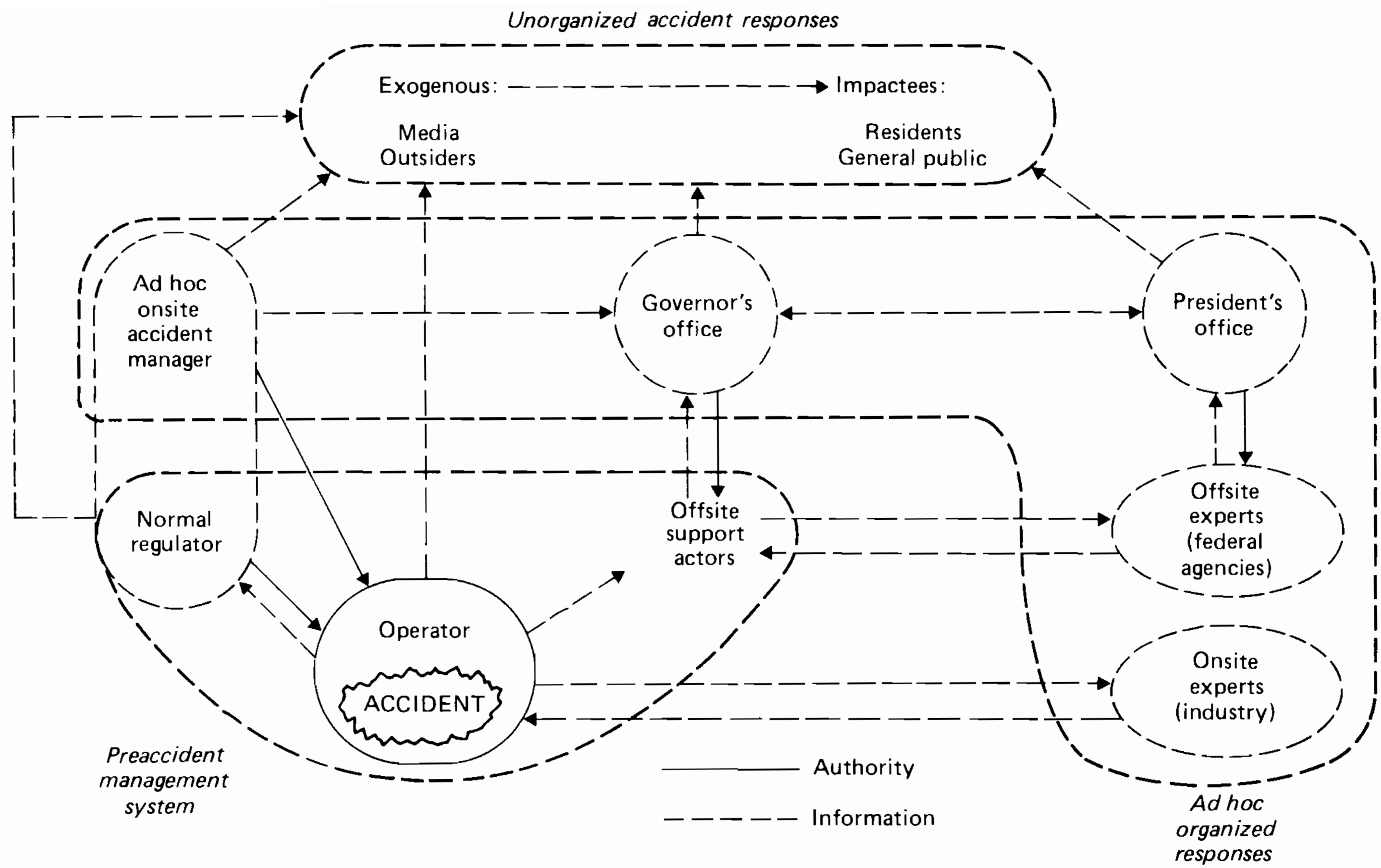

FIGURE 5.2 Principal actors and linkages forming the accident-management system at TMI.

The arrangement at Bravo in Figure 5.1 shows the central role of the accident manager. Even though it was established ad hoc, it functioned well in its relations with the operator, normal regulators, and politicians. Because the normal regulators were part of this ad hoc accident-management actor, and because onsite and offsite responses were under its authority, a prolonged accident would probably not have changed this organizational arrangement.

The organizational setup at TMI shown in Figure 5.2 was the dispersed arrangement that existed at the end of the accident. At the beginning conflicting information sources and a lack of understanding of the nature of the accident led to losses of credibility, publicly in the operator, and politically in the regulator. These problems led to a threeway division of responsibility: an ad hoc onsite manager was created, the Governor's Office was used to direct offsite responses, and the President's Office directed federal agency emergency support. Had the accident persisted, this arrangement could be expected to have been centralized further into one authority handling all responses.

CONCLUSIONS ON ACCIDENT-MANAGEMENT ACTORS AND THEIR ORGANIZATION

Although the experiences of those responding to the Bravo and TMI accidents have been described and compared only briefly, it is possible to formulate some conclusions. As these conclusions have been drawn from only two cases, they may be changed by future experience. However, it is clear that they represent important issues to be dealt with.

A major conclusion is the lack of a priori roles for accident management by all of the actor types involved. For both Bravo and TMI even the accident-response actors were not prepared for immediate active involvement either onsite or offsite. While a major Norwegian response system had been legislated and was being prepared, no plans existed for the interval before the planned system could be completed. The NRC office at Washington, DC, on the other hand, did not have preparations for active involvement with appropriate backup in an uncontained nuclear accident. The lack of prior agreed roles also extends to the planned use of the normal regulator, the operator, industry and government experts, scientific experts, the politicians, the news media, the outside experts, and those impacted upon by the accident.

The lack of foresight about active accident-management and supporting-actor roles seems to have stemmed from accidents being viewed as preventable. While both the Bravo and TMI accidents were found to have been wholly preventable, both still happened. Thus, one must conclude that technically "preventable" accidents cannot always be prevented and roles must be developed for coping with the unexpected. In addition, since transition periods always exist, it is also important for interim roles to exist, regardless of the posited roles in the end of a transition period.

Accident-management bodies are also temporary, substitute decision-making actors, and they were prominent in both accidents, particularly at Bravo with the ad hoc Action Command for overall management and the Red Adair Company for managing the accident-control process. At TMI the substitute decision makers included the ad hoc active politicians and the ad hoc industry and regulatory responders. The use of substitute decision-making actors raises such questions as authority, responsibility, liability, appropriate alternatives, and future working patterns, all of which impact on the relations between the operator and the normal regulator.

Reliance on substitute actors of any type, whether decision-makers or supporting experts, can lead to difficulty in the postaccident phase. Once the accident is over or otherwise under control, the substitute actor has completed his task, leaving the normal regulator and operator to cope with and adjust to the consequences. In addition, at both Bravo and TMI a temporary investigatory actor appeared in the postaccident phase; such an actor can further disrupt the regulator–operator relations. If substitute actors work through or with the normal regulators and operators, accident management could be reinforced as an issue requiring greater attention by both regulator and operator, and a smoother transition to the postaccident phase would ensue.

Previously assumed exogenous actors were involved in both of these accidents. Politicians, the news media, outside experts, and foreign observers all played important roles during and after each accident. No a priori roles existed for these actors, and one can conclude that they were initially viewed as exogenous by all preaccident actor groups. However, both Bravo and TMI showed that these actor types can play significant roles in accident management and should therefore be integrated into the preaccident, accident, and postaccident plans. Consideration for these actors and assessments of their responses before an accident can lead to greater management effectiveness and reduced stress in the onsite and offsite accident-response actors during the accident itself. Exclusion of these exogenous actors a priori led to unforeseen political consequences on later energy development, alarming news reports, and heightened anxiety on the part of the general public.

One can conclude that a centralized organizational form is needed as near to the accident scene as possible. The TMI accident showed the confusion and loss of political and public credibility that can occur from a decentralized system that is at varying distances from the accident. In addition, such confusion can be abetted through ad hoc arrangements to create a different organizational form during the accident. The loss of credibility can also extend well beyond the accident itself to limit the role of the use of the technology in question, as shown by the current moratorium on nuclear energy in the USA and elsewhere.

In contrast, the Bravo accident demonstrated that a centralized system where accident-response actors and normal regulators are merged into one body can be a workable arrangement. Under this form, news-information sources, directions and advice to the operator, and advice to impactees and politicians are all centralized. In this way both political and public confidence can be maintained even in the face of an evolving or expanding accident with an uncertain outcome.

Another major conclusion from this overview of the Bravo and TMI accidents is that there is a need for research based on systems analysis using social scientists as an integral part of the planning process. Any accident-management system is based on individual and organizational actors, and the causes of the Bravo and TMI accidents have been attributed to weaknesses among the actors responsible for preventing these two preventable accidents. Viewing these accidents from a perspective based on a recognition of at least these six actor types requires a systems point-of-view based on social science. Both the Bravo and TMI accidents reveal that the fundamental human and organizational relationships and values had not previously been subjected to study. Systems analysts and

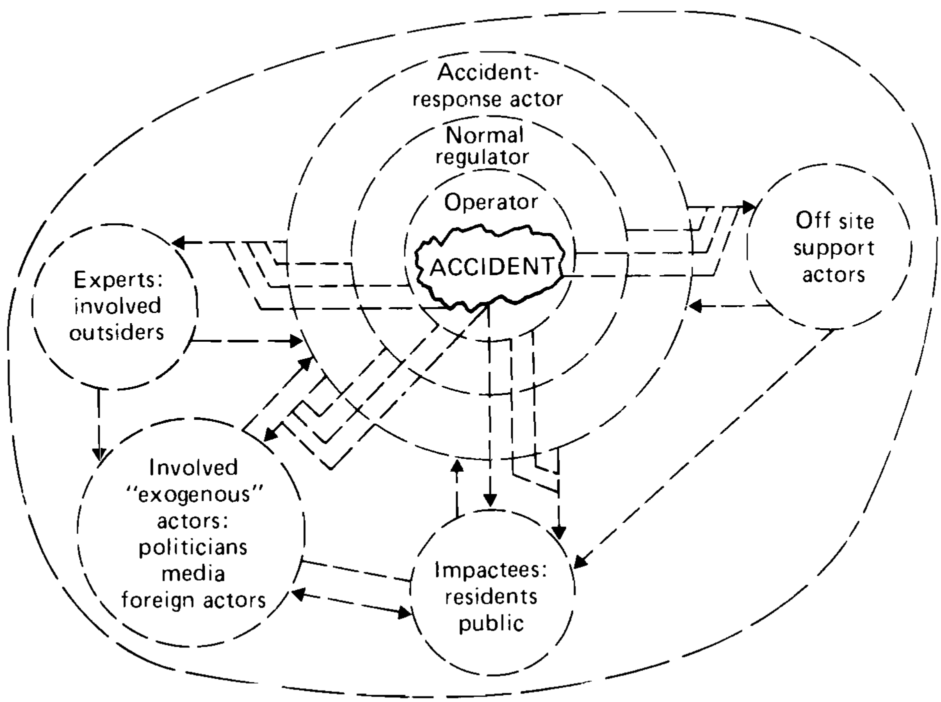

FIGURE 5.3 A suggested accident-management system for recognizing and organizing responses in the preaccident phase.

social scientists should examine their implicit assumptions about doing research and integrate their roles into an applied focus on accidents and their social consequences. Certainly, the findings of such research can and should be an integral part of the structure of a total accident-management system.

Thus, the extent of actual damage to impactees cannot be viewed as the most significant factor in these accidents. Both at Bravo and TMI the offsite damages sustained were nil, yet both resulted in political decisions for temporary moratoria on further development. Technical defenses for containing the consequences of an accident only appear to reduce the immediate effects on impactees. Politicians, the news media, and the general public can generate long-range effects, regardless of the energy benefits involved. Therefore, wider preaccident consultations, open twoway flows of information, and participatory roles for heretofore exogenous actors may be useful in reducing political consequences.

RECOMMENDATIONS ON ORGANIZING FOR ACCIDENT MANAGEMENT

Figure 5.3 portrays an accident-management system that displays a priori roles and linkages based on a centralized organizational form for the actor types discussed in this chapter. Such a management system specifies roles for the responses of all actors before a major accident happens. This framework gives a formal basis for the necessary ad hoc actions and informal bargaining that arise during an accident. The organizational system must be arranged so that the roles occupied and the performances in these roles are rewarded or penalized by an incentive system at least equal to the severity of the consequences expected in an accident. Separation of roles in the preaccident phase and the ad hoc emergence of new roles in the accident phase imply that individual incentive systems can color accident responses more than the needs of the accident as a whole. A more rational a priori system with an integrated set of incentives for integrated management responses is the basis for more effective accident management. The sum of individual capacities to respond to an accident cannot be expected to fulfill automatically the needs for adequate responses. Because ad hoc, unorganized, or exogenous actors will emerge and become involved with a previously organized system in a major accident, it is important to integrate their expected (and unexpected) responses into a total accident-management system.

Regardless of the formal creation of roles among the various actors that can be expected to become involved in a major accident, one encounters professional ideologies from such actors that can inhibit its operation. One such bias is that regulators and operators become enamored of the third-party benefits of energy and tend to lose sight of the third-party costs involved. For example, the responses to intermediate multicause accidents involving the man--machine interface have not been the subject of much study. One reason for this oversight is that the technological prevention of a total or massive accident has occupied much of the research resources. Many references contrast a total accident with total prevention, with the result that little is known about intermediate accidents and their appropriate, alternative intermediate responses.

When it comes to the ideologies surrounding accident management, it seems that the greater the implicit consensus among actors the greater the concern for gaps in their responses. Each organization has a dominant professional bias and its own collective wisdom or "mindset." Such devices are important for minimizing normal uncertainties internal to the individual actor, but these values and assumptions also lead to greater uncertainties within the overall accident-management system. Explicit and implicit value differences exist among the actors that can be expected to be involved in responding to a major accident. The more the implicit values and assumptions separating these actors can be discovered and questioned, the more differences among actors will appear. Such questioning can lead to self-examination among individual actors and collectively as part of an accident-management system. However, the more fundamental issues and need for self-examination, the less each is willing to do so, especially with other actors in the management system. Thus, the externally appointed investigatory body in the postaccident phase plays an essential role in requiring this questioning process and in attempting to see the preaccident phases together as a system of interconnected responses. The real need, however, is to create and structure this fundamental questioning process in the preaccident phase, rather than after an accident occurs.

Figure 5.3, of course, is a static picture, and some process for questioning the values inherent in developing such a system is necessary. Dialectical planning processes are a way of attempting to create a more comprehensive and realistic accident-management system. Such a process can lead to the fundamental questions of which actors should be involved in the system, how they should be involved, and which (unexpected) responses should be planned for before they occur. The preaccident planning approach suggested here could prove useful in determining a priori sources of conflict in ideologies and using them creatively in designing the entire management system. Certainly, a dialectical planning approach is a way to overcome the existence of the rigid "mindset" that the President's Commission [2] found to be at the core of the issues surrounding the TMI accident. In addition, an organizational expert [6] has noted: ". . . we know how to cope with continuous change but not with discontinuous change . . . when discontinuities do occur, they upset things in a big way because then the underlying assumptions of the past no longer apply."

In my research on these two accidents in the oil and nuclear industries, I have found a belief in uniqueness to be prevalent among regulators and operators. Before the fact, each accident was viewed as "impossible"; after the fact, each was viewed as "unique," the result of a particular one-time configuration of weaknesses that in combination led to the accident. Thus, it was assumed that such weaknesses had now been accounted for and that organizational and administrative weaknesses would no longer be an issue. I suggest that the ideology of uniqueness is a myth and that the experiences of these two accidents show that comparative systems analyses of accident management will be useful.

Why should the management of near and actual accidents have been downplayed in the organization and administrative practices surrounding the design, construction, licensing, operation, and servicing of offshore platforms and nuclear reactors? Such a question can be approached partially through two further questions.

1. What are the fundamental professional ideology, administrative outlook, or attitudes toward safety and accident management held by the industry and its regulators?
2. How are complex questions of safety and accident management formed and put forth or merchandized to others by the industry and its regulators?

This short chapter could not hope to deal with these two significant questions; it is my hope that subsequent research on actor behavior can bring penetrating analysis to bear on these questions.

SOURCES OF INFORMATION

The discussions in this chapter are based on material from many sources. Personal interviews with Hans Chr. Bugge (Director of Action Command for the Bravo blowout and Director of the Pollution Control Authority), Arne Flikke (Director of Oil Pollution, Pollution Control Authority), Dag Meier-Hansen (Director of Operations, Oil Directorate), Bjørn Myklatun (Senior Surveyor, Det Norske Veritas), and Torvald Sande (Director of Safety, Oil Directorate) yielded valuable information about the Bravo accident, while Robert Arnold (Director of Recovery Operations at TMI, Metropolitan-Edison, and General Public Utility), Harold Collins (Assistant Director of Emergency Preparedness, Nuclear Regulatory Commission), Oran Henderson (Director of Pennsylvania Emergency

Management Agency), and Dudley Thompson (Assistant Director for Inspection and Enforcement, Nuclear Regulatory Commission) were equally forthright about the Three Mile Island accident. I was present at the briefing arranged for foreign observers by the Nuclear Regulatory Commission on May 21 and May 22, 1979, and also attended the Congressional hearings on the same subject - the Subcommittee on Energy Research and Production, House Committee on Science and Technology, May 23, 1979, and the Subcommittee on Energy and Environment, House Committee on Interior and Insular Affairs, May 24, 1979. In addition to references specifically quoted in the text, many other written testimonies and general sources of information about the two accidents discussed in this chapter are available and were freely used in its preparation. Rather than overburden the text with these, a general bibliography is given at the end of the chapter and this should be of interest to readers who want to study such material more closely.

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5 SUMMARY OF ISSUES ARISING FROM THE BLOWOUT WORKSHOP

David W. Fischer

This chapter summarizes the issues stemming from the workshop on blowout control and management. The workshop addressed issues that were of interest to operators, regulators, and independent experts from North Sea countries; viewpoints were presented in prepared papers, informal remarks, and ensuing discussions. The format for this chapter follows the general structure of the workshop.

NATIONAL CONSIDERATIONS

Economic Background

The economy of a country has much to do with the importance it attaches to oil and gas production, and therefore its attitude to blowout risk and accidents. For example, the oil and gas income from Norway's Ekofisk Field exceeds the income from its traditional fish and agricultural industries and even exceeds the amount collected from personal income tax. Thus, any interruption to oil and gas production is very damaging; indeed an estimate of state income lost during the Bravo blowout was US \$100 million. The importance of this economic factor was stressed in papers by Bugge and by Fairclough.

Other Economic Interests

Each North Sea country has other economic interests that may conflict with oil and gas production; these interests may also be greatly affected by any related accidents. In Norway the fishing industry is widespread and contributes greatly to national income and global dietary requirements; therefore, it sees the impact of an oil slick as potentially catastrophic. This point formed the basis of a paper by Føyn.

Political Implications

All participants in a major blowout expect political consequences; response to a blowout is also regarded by government, the news media, and the general public as a political event. This was borne out both at the Bravo blowout in the Norwegian sector and in tanker spills off the UK. The blowouts triggered discussion on overall oil policy and renewed debate on past environmental and safety conflicts of oil-related developments. A paper by Fairclough showed the political repercussions of the *Torrey Canyon* oil spill.

Political Background

The political situation in a country influences the overall priority attached to oil gas production and any related accidents. In Norway significant opposition to oil development from several parts of the political spectrum (leftists and liberal groups as well as agricultural and fisheries interests) occurred in parliament; this delayed oil exploration north of latitude 62° N. The Bravo blowout happened at the time of this debate and heightened the concern and strength of the anti-oil faction. The political responses to a massive offshore pollution incident were discussed by Bugge and by Fairclough.

Specific Political Interest

Political concern over oil accidents and their consequences is heightened by a blowout or spill. After the Bravo and *Torrey Canyon* accidents, both the UK and Norway formed investigating bodies, presented white papers to their parliaments, created commissions, established research projects, and reorganized parts of governmental machinery to cope with oil accidents. Both Bugge and Fairclough outlined this aspect in their papers.

Social Background

The social character of the region of a country most affected by the oil industry and its related accidents is also important. Both Scotland and Norway have very rural coastal areas with traditional lifestyles, which would be severely affected by sustained oil blowouts or spills. Thus one region suffers the disadvantages of development, while the other regions and other countries benefit. While no paper at the workshop addressed this issue specifically, it did form part of the discussions.

PREVENTIVE ISSUES

Limited Data

Because the number of blowouts worldwide is small, and they are limited to general areas, it is difficult to obtain reliable statistical data for determining accurately blowout risk elsewhere. However, large platforms with large numbers of people demand strict accident prevention measures. Fault-tree analyses are done to try to improve safety, and hazardous conditions can then be recognized and minimized. Fjeld's paper outlined the worldwide statistics available for the last decade and Vedeler's paper suggested the criteria that must be considered if safety during drilling is to be improved.

Human Error

Risk analysis has shown that human error is a prime cause of blowouts. Such errors occur when the drilling crew must make immediate decisions about unexpected reservoir conditions, when they are without adequate supervision, and often when they are tired and under stress, such as early in the morning. Improvements in the level of supervision, reservoir prediction, crew training, the reliability of safety valves, and reporting procedures will all help to avoid accidents. Papers by Fjeld and by Vedeler summarized some key factors in preventing blowouts, including that of human error. The paper by Bøe considered the broader aspects of the human–technology interface.

Methods for Risk Prediction

Fault-tree analysis is the basic tool for predicting the probability of failure, and consequences analysis is used for estimating damages associated with such failure. These tools serve as a device for communicating between interested bodies and establishing control procedures. However, it is difficult, time-consuming, and expensive to undertake such studies, and their usefulness is often questioned because of the inability to quantify the actual risk. Thus oil companies have so far rejected the need for such studies. A paper by Fjeld and Myklatun summarized the steps in a total risk analysis, while Lathrop's paper provided the theoretical basis for such an analysis.

Disclosure of Information

The use of risk analysis is inhibited because companies and some governmental bodies withhold information. This reluctance to share information is for the benefit of commercial interests – the stockholders of companies or the clients of government institutions. These points were raised during the discussion and were found to militate against an adequate risk-management system. For example, it was stated that Norway has tried for five years to get more information to enhance safety evaluation. One strategy for getting more information is to work with each individual company, rather than an association of companies.

Blowout Preventer Valves

Blowout preventer valves (BOPs) proved to be of differing design and quality. A direct transfer of experience from the Gulf of Mexico was insufficient for North Sea operations and conditions. The design, functioning, and testing of BOPs were thrown into confusion. The susceptibility of these valves to fire and explosion was particularly important. The use of failsafe design and materials was considered necessary, and work is to be directed to this end.

Safety Philosophy

Other issues emerging during the discussion were how much safety is "enough" and how should safety questions be decided. Company and UK regulatory authorities opt for rather general approaches to safety, while Norway now requires more specific measures. All at the workshop agreed that, while too detailed a specification of safety requirements can be costly, the problem of insufficient safeguards, especially related to human behavior and matching components is very real. To rely solely on operator experience as the basis for avoiding accidents and near-accidents seems unwarranted. The safety limits of an individual country seem to be decided on the basis of past experiences and the economic and political interests affected. Papers by Bøe, by Bugge, and by Fairclough touched on this point. Also a paper by George and Read reviewed how safety measures in offshore oil production evolved.

Design Conflicts

A problem of concern to regulators is the adequacy of the total system design. In Norway one such issue has been the use of a separate platform for the crew rather than a reinforced crew compartment on the drilling platform. Another such issue has been how to improve the design of safety systems to match increased production; for example, at Bravo the fire-fighting vessel spray did not reach the platform deck. A recent report has shown that maintenance of large North Sea platforms is becoming more difficult and costly because the stress on platforms is greater than that assumed by the designers. Safety valves used in the Gulf of Mexico are unsuitable for use in the North Sea. The design for efficient production can conflict with the optimum design for accident prevention; for example, covering well-heads in concrete for fire and dropped-object protection hinders ease of well capping. While many of these points emerged only in the discussion, a paper by Bøe considered the factors involved in designing a safety-conscious offshore operation.

Operator–Regulator Relations

It was considered essential for the operator and the regulator to maintain good communications. A difficulty is to get the platform crews to use established procedures to keep the regulator well informed, and to pass on ad hoc information. Designation of individuals, well known to the platform crews, to receive up-to-date reports and information was seen as important if communications are to be improved and if the confidence of drilling personnel is to be gained and unsafe drilling conditions are to be promptly reported to the regulator. On the other hand, the regulator should not interfere in worker–management relations. However, in both the USA and Canada, good working relations between drilling crews and regulators allow the regulator to keep management informed on ways of improving safety. This situation helps to get near-accident feedback into the routine management of actual drilling. All agreed that communications between operator and regulator improve after a disaster, since both parties suffer during such an event.

Safety Research

North Sea operators and countries evince more interest in safety research than was formerly the case. Norway has launched a major four-year offshore industrial-safety research program with the emphasis on human functioning in a sociotechnical system and comprehensive risk analysis of offshore activities. In addition, specific technical solutions and safety procedures are to be devised for preventing and responding to offshore accidents. A systems analysis was the basis for the research design. Finally, Norway's experience with the Bravo blowout led to requirements for improved training of drilling personnel, more detailed regulations for technical inspection and control of drilling operations, approved operator control plans, and research on well-maintenance problems. Bøe's paper contained research suggestions, and Bugge's paper noted a list of current safety-research topics.

WELL-CONTROL ISSUES

Contingency Planning

The role and degree of contingency planning was at issue during the workshop. One regulator felt that a systems analyst could do far more harm than good through using faulty assumptions and relying solely on available data. On the other hand, an analyst argued for greater specification of the alternatives available before accidents happened, in order to reduce "ad hocracy." The problems of advance planning are compounded because accidents rarely happen in the same way and even the best plan cannot provide total control over the necessary responses. A point stressed, however, is that, once a blowout has occurred, timing may not be a problem, because of the accepted duration of blowouts. Therefore, greater reliance was placed on general contingency plans, even though Norway was moving toward greater specificity. Norway favored standardized, specific plans, while the UK preferred more diverse arrangements prompted by the operators involved. While it was seen as "dangerous" to specify safety responses too soon, it was also seen as equally dangerous to rely solely on operator experience and self-interest. Examples of factors for contingency planning can be seen in papers by Killerud and by von Winterfeldt.

Fire Fighting

The highest priority in well control was given to fire fighting, in order to protect the platform during a blowout. The issue was how such protection activities are to be carried out. One way was to design a fire-extinguishing system as part of the platform itself, including a device that would inhibit the spread of fire – filling structural members with water or spraying concrete on them. Another alternative was using a vessel to fight fires that would be permanently stationed in the drilling area. In order to reduce the expense of this standby vessel, suggestions were made on how it could be used for other purposes, such as diving and inspection. Whether or not this would create difficulties has yet to be decided. In addition, a problem was seen in that the largest available fire vessel will not meet the demands of the largest platforms planned. Concrete-covered wellheads inhibit the ability of a water spray to fight fire, even though this covering gives greater protection to the wellheads from dropped objects. Response times for fire-fighting vessels were also known, and some research was under way on the costs and benefits of various delay times. The effects of fire on safety valves was also seen as an important issue, since they may become fused and incapable of function.

Well Capping

A primary method for controlling wells is capping to stop the flow. Various views existed on how this capping was to be done. Operators tended to see each blowout as unique and to rely exclusively on outside specialists such as the Red Adair Company. In Norway greater oil company expertise, planning, and capping equipment are now seen to be necessary at all times on the platform. The matching of equipment is also a problem; the scale of a barge to be used as a working platform must be matched to the platform it serves. Fireproofing and protecting the wellheads from dropped objects hamper capping operations, and encasing the wellcasing and structural members of the platform with concrete hampers the detection of blowing wells. An undersea wellhead creates additional problems if capping is to be attempted; little research has been done on this problem. Research on well capping is now increasing and more attention is being paid to supporting facilities and equipment; however, platform design has not yet been influenced by capping requirements. In particular, ease of fire fighting conflicts with ease of capping, and the new large concrete platforms make detecting the blowing well and capping even more difficult.

Relief Drilling

The major way to ease pressure on a blowing well is to drill a relief well into the geological structure. However, relief drilling is difficult in bad weather and when mobile rigs are unavailable. A suggestion was made that a relief drill should form part of the larger platforms; another suggestion was to maintain a log of available rigs or require the presence of two drilling rigs in remote areas. When the North Sea becomes solely production-oriented, it may be necessary for the regulator to acquire one or two mobile exploration rigs for possible use as relief rigs. Safety measures during relief drilling were seen to be important, as well as problems of weather if a barge containing pumping equipment was hooked to the relief rig. Given the high productivity of North Sea wells and the degree of concern for the marine environment, relief drilling was seen to be an urgent necessity to satisfy politicians that all available precautions were being taken.

Degree of Readiness

Some concern was evidenced over the requirement for major preparations in advance of an incident. A priori requirements were seen to depend on standardized equipment and to lack the ability to adapt to an emergency. Also, single-purpose equipment was too expensive to be simply on standby, whereas multipurpose equipment was even more expensive in itself. Since operators tend to have differing operating philosophies, and since they view each blowout as unique, there has been some resistance to standardization. For a small country, however, there is a need to standardize procedures and equipment and to establish a standby capability.

Scene of Well Control

The distances between the scene of an accident, company headquarters, and the regulator were seen as hampering well-control operations. Perceptions of the problems, and hence workable solutions, may differ because of this. Obtaining good communications and adequate company expertise at the scene of the accident were regarded as important factors in well control.

Information Availability

Since a major blowout has political repercussions, the availability of current and accurate information to the government, public bodies, the news media, and the general public is important. The necessity is both to get and to give timely and accurate information to support good decision-making. To provide such a flow requires good working relations with the operator, separate emergency communication channels, full communication facilities, the confidence of the news media, good facilities for reporters, and swift access to operator and government. Information is also necessary to counter opinion based on previous blowout experiences elsewhere that may be misleading with respect to the new event. In addition, knowledge of the relation of blowout information to overall oil policy is important. Both operator and regulator are affected in the long term by the information retained by the public after a blowout has been controlled.

Role of an Action Command

Discussion was devoted to the question of an ad hoc action command or substitute decision-making body to spearhead a government's response to a blowout. While most agreed that such a body should only observe, advise, support, and approve the oil companies' efforts, differences existed over how such activities were to be conducted and what was the most efficient role for government experts. Differences emerged on whether government experts should remain in their normal chain of command or be under an ad hoc body. There was a warning that such an ad hoc body could make operations more dangerous, because they were independent and isolated from knowledge of day-to-day regulatory procedures and practices. Following the Norwegian experience at Bravo, it was suggested that representatives on an action command should also function in day-to-day regulatory roles. If a separate group were brought in, such as a special quasi-military unit trained in making quick decisions, the danger exists that the government might take over the entire operation, and potentially damage future regulatory and operational procedures, communications, and trust. A government takeover might also give the impression that operators are less responsible for impacts resulting from their activities. However, the Bravo experience showed that use of an ad hoc body set up by the government worked well to provide timely advice to Phillips. In addition, the potential for a more active government role in that situation existed if it had been deemed necessary.

POLLUTION-CONTROL ISSUES

Pollution Threat of Blowouts

While it was conceded that blowouts can cause a significant amount of pollution from spilled oil, an opinion was held that tanker spills were a far greater menace. A representative of the UK felt that Norwegian tankers, and those from other countries to an even greater extent, posed a greater pollution threat to UK waters than blowouts or chronic discharges. Norwegians however, showed greater concern for oil pollution from platforms. Both of these perspectives reflect the threat each country faces. The UK is now experiencing tanker traffic moving almost 300 million tons of oil a year along its south coast and has also experienced major oil spills from tankers such as the *Amoco Cadiz*, *Eleni V*, and *Christos Bitas* in 1978 alone. Norway, on the other hand, has a comparatively small tanker traffic along its coast, but does have oil drilling that extends into its northern waters. While the paper by Fjeld saw a relatively low threat of drilling pollution risk, Norwegian officials stressed that, when an accident does occur, its effects can be sudden, massive, and concentrated, with impacts going well beyond pollution.

Biological and Ecological Impact

Differences in scientific opinion existed over the impact of spilled oil on the marine environment. Some felt that biological research would not be able to answer all the questions on impact before the North Sea oilfields were exhausted. Others quoted past research showing that spilled oil seemed to have minimal immediate impacts and no lasting effects. However, it was feared that oil might have great long-term effects on both fish and their habitats, even though current research had not yet revealed such effects. All agreed that the severity of impacts depends on the type of oil spilled, and where and when it is spilled. While the papers by Cowell, Føyn, and Morris showed some of this concern, the discussions on these papers evoked sharp differences of opinion.

Economic Impact

The enormous cost of attempting to clean a patch of sea was of great concern. Given the lack of knowledge about environmental impact, could this cost be justified? The increased costs incurred by oil companies in using mechanical pickup equipment on government orders were deductable from government revenues, though companies had to make a contribution to the government in support of general cleanup operations. In the Bravo incident the amount of oil collected was insignificant compared to the cleanup effort mounted. In addition, of course, the seas dispersed the spilled oil naturally, so that within days of the blowout few traces of oil could be found. While no paper addressed this issue, discussion was directed to the cost-effectiveness of mechanical cleanup. However, comparison of the costs of environmental precautions to their known effectiveness is a value judgment because, if only the narrow yardstick of strict costing is applied, many important environmental measures will never be implemented.

Political Impact

Given the political repercussions of a blowout, it is important that the pollution threat is seen to be tackled with great vigor, even though existing mechanical equipment is generally ineffective on the high seas. While most participants agreed on the lack of effectiveness of mechanical pickup equipment, considerable disagreement existed over its use regardless of its overall effectiveness. It was held that all available effort should be expended, since the government, news, media, and general public expected such a deployment, and some oil at least would be picked up. Another view was that those responsible should simply say it was better to let the oil slick break up naturally without a cleanup effort. Between these two extreme viewpoints, some felt that further research and development was necessary. Finally, one participant noted that all countries believe the best pickup equipment to be made in their own country!

Weather Conditions

A stormy sea hampers a working barge acting as a platform in a well-capping operation, makes towing of a relief rig impossible, and stops the use of mechanical pickup devices for collecting the oil. On the other hand, such conditions increase the natural dispersion of the oil. Depending on the location of the blowout, the productivity of the well, the direction of the currents, and the extent of the storm, there is a possibility that little oil pollution will approach the shore even if nothing whatsoever is attempted. Therefore, some discussion centered on the question of weather conditions and if specialized equipment was necessary to respond to an isolated blowing well far offshore.

Worst-Case Statistics and Planning

Considerable attention was devoted to the question of the worst case. Regulatory assumptions might take every parameter to an extreme, such as assuming more than one blowout, with each blowing oil at a rate of 15,000 tons per day for 100 days until relief wells are drilled. Such a scenario would ignore blowout experiences elsewhere, the effects of rough seas in speeding natural dispersion, natural bridging of the well, evaporation of oil before it comes in contact with the sea, etc. However, worst-case statistics are favored by the regulator in order to inform politicians of the worst damages that can be expected so that there will be no additional shocks to follow. The counter argument by the operator is that politicians will take the worst case as deterministic, rather than seeing it as having a statistically low probability, and then call for onerous restrictions on all oil operations. The question of the most responsible course of action open to the operator, regulator, fisheries expert, and others was debated. The question of statistics was discussed to some degree in the papers of Fjeld and of Flikke.

Mechanical Pickup

Discussion centered on the efficacy of booms, skimmers, and vessels currently used to capture and collect oil. While some felt that mechanical equipment was of no use in the high seas, others supported the use of such equipment as part of a continuing research and development program, even though the amount of oil actually picked up might be quite small. For example, during an openair blowout in the North Sea, roughly 35% of the oil will evaporate before coming into contact with the sea, and this residual amount will be further reduced by over half owing to natural dispersion and further evaporation. In time this amount will be further reduced by natural means, leaving only 5–10% that may pose a threat to key areas. At later stages emulsification may again increase the total volume of the oily liquid. These natural changes affect both chemical treatments and mechanical pickup methods. Difficulties encountered with the latter include mounting such an effort, owing to the problems of coordinating the number of units involved, matching different types of equipment, replacing malfunctioning units, and the low peformance compared with manufacturers ratings. Equipment capability and compatibility remain problems. The general view was that a mixed response of mechanical and chemical techniques offers the most effective strategy, although not all fishery experts agreed.

Chemical Dispersion

Chemicals of low toxicity are used to aid natural dispersion into the water column of oil spilled on the sea surface. Using such chemicals remains controversial; Norway does not condone their use except for saving human life and platforms. The Norwegian view is that the long-term effects on fisheries of chemicals in the water column are generally unknown. However, the UK view is that chemicals are known to be effective dispersants and have lesser effects on marine life in the water column than on life on the sea surface or inshore. Differences in toxicity between laboratory and experience were also noted, as well as differences in the impacts in open seas and along the shore. In the Norwegian view, more research on dispersants was needed to show their effects on marine life. In the UK the prevailing view is that sufficient research has already been done to show that dispersants do not pose an ecological threat of any significance offshore. However, all agreed that further research is necessary if decision-makers believe that recommendations about chemicals are solely theoretical and unsupported by data. Papers by Cowell and by Føyn provided some background for these points.

Burning Oil

A blowout in the USA was of considerable interest. Here the oil and gas were deliberately ignited to limit marine pollution. This ignition resulted in a burning oil slick that evaporated most of the oil. No capping operation was attempted and relief-well drilling was used to stop the blowout. Burning is a means to reduce oil pollution significantly, but the reduced damages from such pollution must be balanced against the damages suffered by the platform in the fire. The large-scale and complex multioperation platforms used in the North Sea are far more costly than the simpler platforms in the Gulf of Mexico. Given the rapid natural dispersion of oil in the North Sea, the lack of known damages to marine life, the distances of platforms from the coast, and the lack of complaints from fishermen following the Bravo blowout, the ignition of oil and gas blowouts was not considered to be an acceptable strategy.

FEEDBACK ISSUES

Adequate Channels

Experiences with North Sea blowouts show a variety of reactions in the post-blowout period. In Norway an independent Commission of Inquiry was organized to investigate the Bravo blowout, followed by a formal white paper to parliament. A major research project on safety and emergency was launched, which covered the entire oil industry, both onshore and offshore. Finally, a permanent Action Command was organized. In Denmark no formal measures were taken after the Maersk blowout, but a permanent emergency response group is in the process of being organized. In the UK the existing system was strengthened and the bilateral agreement with Norway was also improved. However, the Select Committee on Science and Technology of the UK Parliament has severely criticized the state of UK readiness and the total dependence on chemical dispersants. As a result, a Marine Pollution Control Unit has been created in the Department of Trade.

Research Priorities

Norway is the only country represented at the workshop that instituted an overall national research project based partly on its blowout experiences. This high-priority program concerns human behavior in relation to sociotechnical systems. It is designed in part to make a comprehensive risk assessment of offshore activities, and to specify technical methods for preventing and containing blowouts. Attention is being paid to using the results of this research to improve procedures on safety, surveillance, and accident response for both the oil industry and government.

Standardization and Specificity

Where safety is concerned it is difficult to strike a proper balance between individual preference and standardization. If too many regulations and standards are issued, a loss of personal initiative can result and staff feel they are following a dull, purposeless routine. On the other hand, too much personal freedom can engender unacceptable operational risks, even though communication and response may be excellent. Since the purpose of good regulation is to feed accident information back into routine management procedures at minimal cost, it is important for each country to strive to achieve its own particular balance in this respect. Norway, a small country with limited regulatory resources, is moving toward substantial standardization, a position the USA has also adopted. The UK, however, has not standardized regulations and consistently opposes moves to do so. The paper by George and Read considered this issue.

Updating Contingency Planning

Mandatory periodic meetings between the government and industrial bodies involved in emergency response is a method Norway uses to update its new Action Command. In the UK informal contacts are used to update contingency planning. Whatever means is favored, the process of integrating the lessons learned from blowouts and tanker spills into emergency response plans must be a continuous operation. Incentives must be found to maintain attitudes of constructive criticism toward emergency plans, rather than allowing them to drift into rigid systems based solely on accepted principles.

Science and Decision-Making

The role of scientists and management specialists in relation to decision makers was discussed although no conclusions were drawn at the workshop. Several problems were pointed out; for example, one regulator was concerned that scientists were playing too great a part in drawing up regulations. He considered that decision trees could be misleading, since the assumptions used in their construction are often not stated and not enough information is provided to formulate alternative branches. Other controversies included the relative values of nonspecialists and specialists, basic research versus applied research, and data-based solutions versus educated guesses. These are all factors that a decision maker must take into account before making an overall assessment and final decision, even though himself under stress from the emergency, political pressure, and the news media. Integration of a working scientist into the specialized emergency response team was also discussed, but it was generally thought that a separate team working in parallel with the responsible decision makers was better. The relative roles of systems analysis and more specialized scientific techniques were considered in an effort to ensure that they complemented each other rather than caused conflict or duplication. The decision makers favored closer ties with scientists and were concerned that scientists should bear greater responsibility for their statements; only in this way would their advice improve since assumptions made would be more closely questioned and clarified.

ADDENDUM

During the period between the blowout workshop in April 1978 and the publication of this book another major blowout occurred, at the now-infamous Mexican Ixtoc well in the Gulf of Mexico. Two Norwegian organizations were involved as technical advisors to Pemex, the Mexican national oil company, which owned the blowing well. Statoil, the Norwegian national oil company, and the Norwegian State Pollution Control Authority advised Pemex on oil-spill collection methods.

Considerable "discord between Pemex and Statoil as to strategy" existed; however, several valuable lessons were learned [1, 2] including the following.

1. Relief-well drilling was a failure in that the relief-well bores did not locate the blowing well, even though one relief well was within 12 meters of it. This must, in part, be attributed to the infrequent well logging – every 400 meters – by Pemex. In Norway a well must be logged every 90 meters.

2. The blowing oil did not ascend with the gas but spread in a large ring at a depth of 50 meters and formed a stable emulsion before it reached the surface.

3. Dispersants had much less effect on this emulsion than they would have on oil, and the use of dispersants hindered oil-recovery operations.

4. Mechanical oil recovery proved effective only for wave heights up to 1.2 meters. In Norway requirements still exist for mechanical collection in wave heights up to 3 meters. Also, oil droplets dispersed as much as 12 meters down into the water column, so that mechanical collection could not prevent pollution of the coast.

5. Mechanical oil recovery is a difficult operation, requiring good leadership, seamanship, ships, and equipment. These conditions did not exist at the Ixtoc blowout, so that recovery was hindered by these shortcomings. Only 4.5% of the oil was recovered even though there was good weather and good equipment was available.
6. Waiting until oil pollution reaches a given nation's territorial waters hinders a possibly more effective response by another nation as freshly spilled oil is easier to collect.
7. The inability of the blowout preventer (BOP) to cut through the drill collar showed that BOP technology is not yet fully adequate.

The effect of the Ixtoc blowout on Norway was to raise questions again about the proposed North Sea drilling program north of latitude 62° N. The Norwegian Ministry of Oil and Energy asserted that the Mexican experience was not directly applicable to North Sea conditions and that the lessons learned in Mexico have already been incorporated into Norway's planned response to accidents. By 1980 the Norwegian parliament sanctioned drilling north of 62° N, but also demanded greater preparedness for meeting blowouts by limiting the areas and number of wells drilled.

REFERENCES

1 R.H. Westergaard, Norwegian Oil Review, January 1980, pp. 10, 11.
2 Offshore Industry has Vital Lessons to Learn from Ixtoc I Blowout, Offshore Engineer, October 1980, pp. 157–160.

Part Two

Papers from the IIASA Blowout Workshop

6 A NATIONAL PERSPECTIVE ON THE OIL-BLOWOUT PROBLEM

*Hans-Christian Bugge**

NORWEGIAN OIL POLICY: BASIC PRINCIPLES

The main components of Norway's oil-development policy may be stated as follows. It is intended to continue exploration in the Norwegian sector of the North Sea and to exploit at a moderate rate any economic reserves discovered. There is a certain degree of state involvement through the Statoil agency and strict safety regulations are in force. Contingency plans for dealing with accidents (covering issues of organization, equipment, and training) must be drawn up by the operators who are themselves required to take any necessary corrective actions if accidents do occur. Furthermore, operators are urged to minimize regular discharges of oil. Under Norwegian law, the operator has unlimited civil liability for the effects of any accident. The state's policy is to monitor closely all actions taken by the operator and to be ready to take overall control of operations if necessary. There is a distinct preference for mechanical rather than chemical methods for cleaning up oil spills although it is recognized that further development of mechanical equipment is needed.

In terms of possible environmental impact, Norway recognizes the importance of preserving, as far as possible, the present lifestyle, activities, and settlement systems of its coastal areas. Oil and gas operations are to be conducted in such a way that they pose no threat to fish stocks; the more important fishing and spawning areas are shown in Figure 6.1. Development of areas north of latitude 62° N should continue provided that an "acceptably low level of risk" can be achieved.

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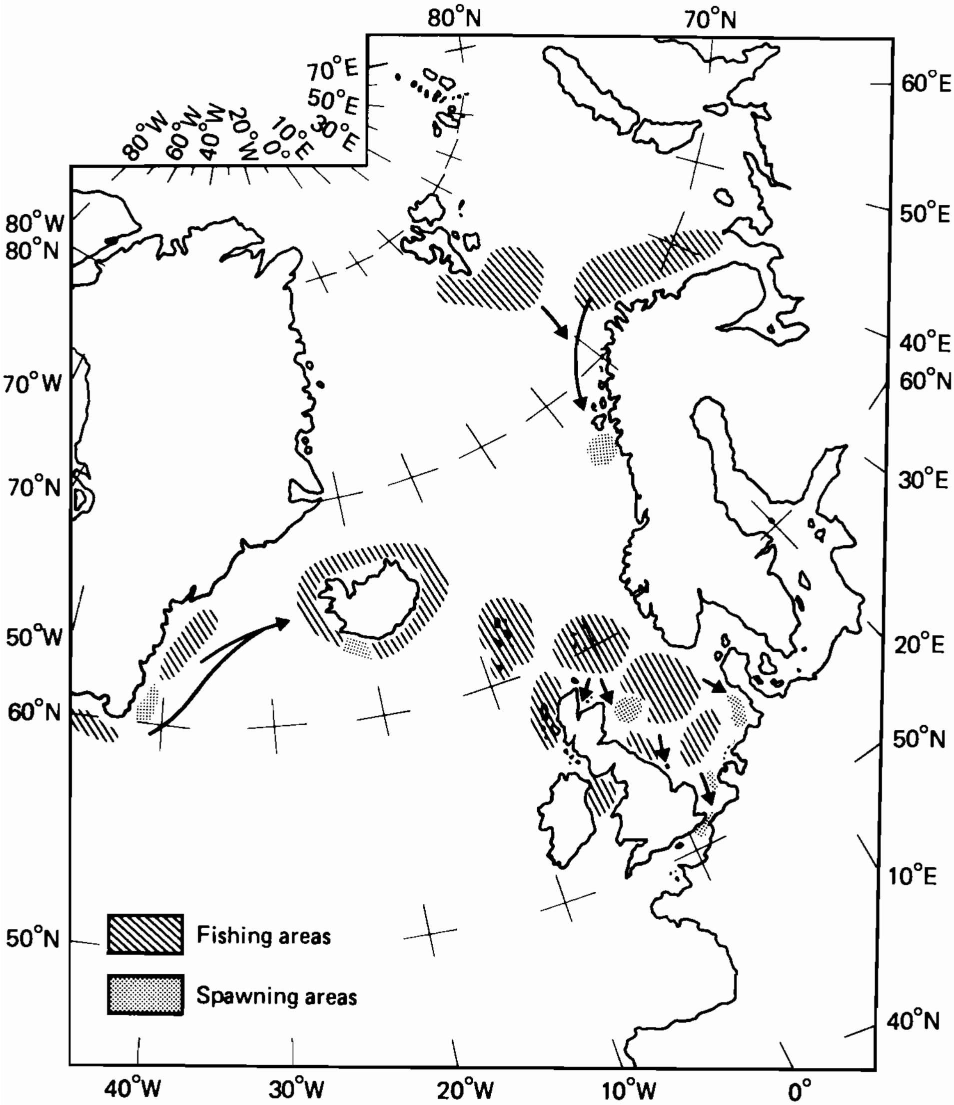

FIGURE 6.1 The main fishing and spawning areas for cod in the northeast Atlantic and the Arctic.

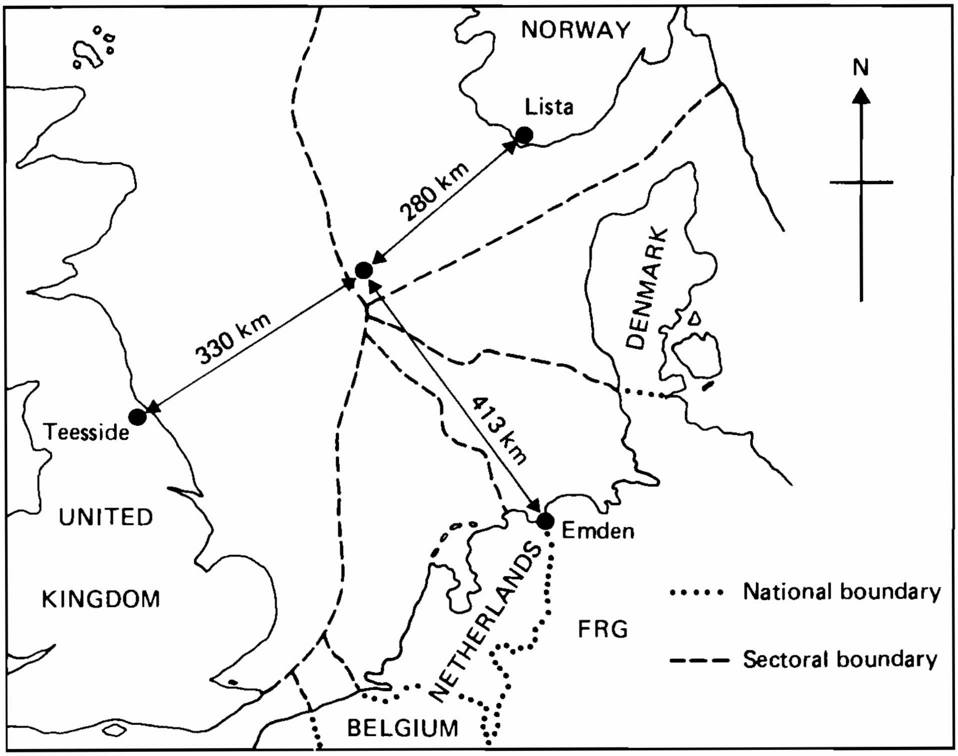

FIGURE 6.2 The location of the Ekofisk field.

EKOFISK FIELD AND THE NORWEGIAN ECONOMY IN 1977

To understand the importance to Norway of the Ekofisk field and of any accidents which could threaten production from the field, a few comparisons may be helpful. In 1977, the rate of oil production from the field was approximately three times the rate of consumption for the whole of Norway. Considered as a sector of the national economy, the field was more important than agriculture and fisheries put together, and, in terms of revenue for the state, Ekofisk was more important than all Norwegian personal income tax.

In addition to the importance of production from Ekofisk itself, the location of the field in the productive southwest of the Norwegian sector (see Figure 6.2) led to its choice as a "gathering center" for a number of other fields in the area. The Norwegian development plan called for oil and gas to be collected, via a complex network of pipelines, from the neighboring Albuskjell, Cod, Edda, Eldfisk, Tor, and West Ekofisk fields and brought together at Ekofisk Center platform. From Ekofisk Center the oil would be pumped along a 350-km pipeline to Teesside, UK, and the gas would travel along a 440-km pipe to Emden, FRG.

NORWEGIAN POLITICAL BACKGROUND

The composition of the Norwegian parliament in 1977 was approximately as follows: Labour, 45%; Conservatives, 25%; Centrists (agrarian), 10%; Christians, 10%; Left-wing Socialists, 5%; and Liberals, 5%. The main opposition to further oil-related development came from the Centrist (agrarian) and Liberal groups and from the Left-wing Socialists. A number of groups expressed mixed feelings about oil development. The main concerns voiced by the political parties opposed to further development revolved round perceived threats to social values, traditional lifestyles and activities, long-established settlement patterns (particularly in coastal areas), and the marine environment. To counter this opposition it was therefore important for the government to have a convincing and comprehensive program, covering both development and safeguards.

THE BLOWOUT AT EKOFISK BRAVO

The Bravo blowout, on April 22, 1977, occurred during a period when general attempts were underway in the Norwegian sector to reduce the danger of pollution and to increase the degree of preparedness for any future accidents. It also coincided with active political debate in the country on the advisability and correct nature of drilling programs north of latitude 62° N.

The Norwegian Minister for the Environment made an immediate decision to set up an Action Group incorporating, under a single leader, all those involved in responding to the accident. The Action Group was the direct representative of central government; although in practice it left prime responsibility for managing on- and off-site consequences of the accident to the operator, the Group was solely responsible for all official statements to the media and had a priori authority to take over direct management of the accident if it deemed this necessary.

The main decision of the Action Group regarding well control was to start both capping and relief-well drilling simultaneously. For pollution control, the Group decided to use only mechanical pickup methods; it mobilized those bodies responsible for shore protection and organized continuous surveillance of the oil slick's progress.

Main Elements of the Blowout Contingency Plan

The Norwegian contingency plan for blowouts stressed the importance of correct operational procedures to prevent accidents from occurring in the first place. In the post-blowout phase, a number of functions were identified. The plan foresaw that, immediately after any accident, accurate and rapid provision of information would be at a premium; fire prevention and evacuation of personnel would be urgent necessities, as would the establishment of the Action Group. Measures to stop the flow of oil or gas, involving capping, relief-well drilling, or fire fighting, would need to be put into effect. To prevent the situation from worsening, the contingency plan identified actions involving cooling down the blowing platform, ceasing production on neighboring installations, designating safety zones around the accident site, regulating the sea and air traffic in the area, and preparing medical facilities and hospitals. Action would also be needed to reduce the environmental impact of the accident and combat any oil spill. Finally, the contingency plan foresaw an important function, particularly for the Action Group, in collecting and disseminating information, involving the operator, the government, the general public, the news media, and other parties.

Immediate Consequences of the Bravo Blowout

Fortunately, there was no fire or explosion at the Bravo blowout and no loss of life. The blowing well was capped within one week. Some 21,000 tons of oil were released during that period; approximately 800 tons were recovered using mechanical methods. No oil reached the shore and no complaints were received from fishermen; it is thought that the immediate damage to the marine environment was insignificant. The economic loss was estimated at approximately US $100 million.

Political Responses to the Bravo Blowout

An independent commission set up in Norway to investigate the causes of the accident reported in October 1977. The Action Group set up by the government also submitted a report, in December 1977. After consideration of these and other inputs, the government presented a White Paper on accident control and prevention measures to the Norwegian parliament in April 1978. The measures suggested are outlined below.

MEASURES FOR PREVENTION OR CONTROL OF FUTURE ACCIDENTS

To try to prevent future accidents the Norwegian government pointed to the need for improved training of oil-company personnel. It introduced new regulations for the technical inspection and control of offshore operations as well as guidelines for the operators' own control measures. More particularly, it proposed a thorough study of problems arising during well-maintenance operations.

As part of its preparations for any future accidents the government decided to organize the Action Group on a permanent basis. It recognized the need to evaluate the total amount of emergency vessels and equipment required as well as the necessity of further research and development on stopping the flow and collecting the oil spilled. It urged that the equipment and organization for dealing with oil spills should be strengthened in both the public and private sectors. Finally, it recommended analyses of the eventual fate of oil spilled from different locations in the North Sea and advised that work should proceed on models of the drifting and evaporation of spilled oil.

More general lessons learned from the Bravo blowout suggested that a wide-ranging research program on emergency situations and safety was advisable. Such a program would include a study of man's functioning in a sociotechnical system; specific solutions to various technical problems; operating procedures and degree of surveillance and their overall impact on safety standards; the reaction of personnel to emergency situations; and finally, a comprehensive risk analysis of offshore activities.

7 PREVENTION, REGULATION, AND RISK

Bjørn Vedeler, Svein Fjeld, Bjørn Myklatun, Carsten Bøe, Dag Meier-Hansen, H.R. George, A.D. Read, Kai Killerud, and John Lathrop

7.1 SAFETY ASPECTS OF OIL BLOWOUTS*

This section was originally called "Safety Standards and Oil Blowout Risks" but subsequently altered to the present title. This change perhaps reflects the difficulty of reviewing such a complex subject as safety standards and blowout risk: probably the best that can be achieved is to shed some light on the problems involved.

Blowout risk can be defined as the product of the probability of a blowout occurring and its consequences; the latter would include loss of life, economic considerations, and pollution. The emphasis here will be on practical matters since theoretical aspects have been extensively considered elsewhere. Before considering safety measures against a blowout, it is necessary to examine the probability of such an event and the potential consequences for the area in question. Basic differences of opinion exist which are usually resolved on political grounds, and the standards applied will thus be different in various parts of the world.

The blowout at Bravo in the Ekofisk field had a strong emotional effect on the Norwegian population, and hence generated political overtones. Even before the final outcome was known, it had already been decided that existing safety standards were inadequate, and money was allocated for research and the construction of coastal defenses against drifting oil slicks. A large number of research projects are under way to define in detail the risks inherent in all stages of offshore oil development and to suggest ways of reducing these risks. In the meantime, reports on the Bravo incident have indicated that, owing to a series of lucky coincidences, the effects of the blowout were very small.

Starting from the data that are available today, the Gulf of Mexico is the only area where offshore oil drilling and production have been going on for long enough for assessments of blowout risk to be meaningful. Since this is also the only area from which enough statistical data are available to establish blowout probability, it is natural to start from here and see how the experience gained can be applied to operations in other parts of the world.

In the Gulf of Mexico one blowout occurs in the drilling phase for every 400 wells drilled. In the production phase, however, this decreases to one blowout per year per

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4,000 producing wells. Only a very small fraction of these blowouts caused loss of life. Almost all of the blowouts were "killed" or stopped of their own accord before significant pollution had taken place. However, it must be borne in mind that in the Gulf of Mexico oil is produced from fairly small reservoirs with low productivity; in these circumstances a well is very likely to blow itself out soon after a blowout occurs. In the North Sea, on the other hand, reservoirs are much larger and wells much more productive. In the Norwegian sector it is not unlikely that a well could blow out 10,000 tons of oil per day. The productive zones are also in areas where self-killing is not likely to take place. Therefore, a blowout in the North Sea may last much longer than would be the case in the Gulf of Mexico. The consequences of a blowout in the North Sea are thus more serious and widespread. If the same level of blowout risk accepted in the Gulf of Mexico is to be applied to North Sea operations, then it is clear that steps must be taken to significantly reduce the probability of such an occurrence.

Before the risk can be reduced, it is necessary to carry out a fairly detailed analysis; such a risk analysis is outlined in Section 7.2 and will therefore not be elaborated here, but the results of this type of analysis will be discussed.

During drilling and in the production of oil and gas, special safety systems are used to prevent blowouts. It is nearly always a combination of several circumstances that leads to a blowout. However, the ultimate causes of a blowout are not always easy to define. They are usually connected with unexpected release of very high-pressure oil or gas (releasing reasons) or the simultaneous failure of equipment, planning, or reactions.

The most common releasing reasons are as follows.

1. Reasons connected with the reservoir and the local geology: shallow gas pockets, high-pressure zones deeper down, lost circulation, and damage to piping or equipment from corrosion or wearing out.
2. Reasons connected with difficult operations: drilling into another well, suction resulting from withdrawal of drill string or production pipe, and incomplete stabilization of well during stages when the amount of safety equipment has been reduced (e.g., during some kinds of maintenance).
3. External reasons: falling objects, drifting, fire, explosion, collision, collapsing foundations, and natural forces (earthquakes, waves, winds, etc.).

In the same way, simultaneous failures can be listed as follows.

1. Failures of equipment: control equipment and safety equipment for drilling and production.
2. Failures of planning: insufficient planning of well, mud too light, ring void not full of mud, and incomplete cementing of lining pipe.
3. Incorrect reaction to unexpected situations: that is, human error.

With the reasons and failures identified, the next step is to determine which items demand special attention. Section 7.2 defines certain key areas, but as the matter is of such importance it will be considered further here.

Vital Factors

Geological Information

Before drilling is started it is necessary to have the best available knowledge of the geology of the area. This can be gained by a combination of several methods. Shallow seismic surveys reveal shallow gas pockets, while deep seismic methods give maximum information on the deeper layers. Preliminary drilling in areas with shallow prospects in well known foundations may reveal abnormal pressures in deeper layers.

Planning of the System as a Whole

For better design of platforms it is necessary to know more about the physical conditions of the actual area. More environmental data are needed. When planning large, complicated platforms the possibility of external factors causing blowouts must be considered and minimized. Platforms must be designed in such a way that fires and explosions cannot reach the wellhead, and wellheads must also be protected against falling objects and other possible blowout dangers. Improved standards for platform layouts are essential. Where automation is not possible, information must be simple and clear, and alarm systems robust and with uncluttered panels to reduce the number of faults. Design standards are long overdue.

Critical Mechanical Components

The safety valves that are placed in the production pipe need to be developed further. New designs to improve the working life of such valves are highly desirable and design standards are vital. Installation of sand filters and sand detectors reduces the danger of pipes and valves wearing out. A requirement for such components should form part of any future design standard.

Use of Automation and Information Systems to Reduce Human Error

Automation can in many situations improve reliability by factors of 100 to 1,000 over that of human beings, but this improved reliability can only be guaranteed for equipment tested over long periods. Standards should thus be set for determining the mean time before failure for components of systems that are to replace human beings. Measurement of well parameters during drilling is very important here. The relevant technology has been under development for some years, and similar methods are also applicable to the monitoring of the well during insertion or withdrawal of the drill string or production pipe. In the USA an automatic drill rig has been developed where most of the operations to remove or insert drill pipes are automatic and only supervised from a control room. This automation reduces the probability of a blowout as mud can be circulated when the drill string is pulled out. The machinery can be programmed for automatic refill of the well and kicks can be handled much more easily. The exposure of personnel to bad weather is reduced and drilling can be made explosion-proof.

Education of the Crew

It is well known that the training and education of offshore personnel is very variable. It is essential to provide better, more systematic training and education to platform crews.

It is also necessary that important and difficult jobs be only filled by technically competent and authorized individuals. Again, the necessary standards are at present lacking.

Control Procedures

Major errors of judgment have in many cases been the reasons for blowouts. Such errors cannot be eliminated by improved safety procedures but they can be reduced in number by stricter control. The control of drilling programs and equipment should be carried out by an authority that is independent of the operating oil company, although the latter should, of course, also carry out a coordinated control procedure of its own. The recording of all observed events on magnetic tape would significantly improve control procedures. Standards for such data and data banks are essential.

Conclusion

The standards that already exist in some areas of the world may be adequate for their purposes. In other areas, however, new standards are necessary to lower the risks to a politically acceptable level. Norway seems to be just such an area; it is to be hoped that the probability of a blowout in the Norwegian sector of the North Sea can be reduced to one-tenth of that in the Gulf of Mexico.

7.2 MANAGEMENT AND CONTROL OF OIL BLOWOUTS IN THE NORTH SEA: RISK ANALYSIS FOR PREVENTION*

Efforts to increase safety during the planning, construction, and operation of offshore installations are mainly directed toward reducing the probability of an accident, and containing and reducing the consequences of any accidents that do in fact occur. Risk analysis is an important tool for achieving these ends. A risk analysis involves identifying hazards, analyzing their origin, establishing possible consequences, and calculating the magnitudes and probabilities of these consequences. The purpose of this section is to indicate feasible techniques for risk analyses rather than to detail their conclusions.

Although this type of analysis appears to be an obvious device for developing risk-control programs in offshore operations, it has not, however, been used extensively in the oil industry, but is well established in the aircraft and nuclear industries. The general procedure that is normally followed is given in Table 7.2.1; the methods and resources necessary to perform a risk analysis are included. The subject of a risk analysis can be any mechanical system, activity, or operation.

In risk analyses as outlined above, the scope and degree of detail, as well as the actual method of analysis, will vary greatly from case to case. When carrying out such an analysis it is important to specify the objectives in detail. In the case of offshore operations these may be: to investigate whether the subject under investigation fulfills specified safety requirements; to calculate the level of specific risks; and to identify risks, the critical properties and components that might increase such risk, and to use the results for improving safety. The last objective implies a very positive use of risk analysis in preventing accidents.

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Example of a Risk Analysis for a Blowout on the Norwegian Continental Shelf

General

As mentioned above, it is imperative to have the objectives of the investigations precisely defined. In the present case these included an evaluation of what could be done to minimize blowout risk on the Norwegian continental shelf. The risk can be expressed in terms of oil discharge, or danger from fires, explosions, etc. In this example, the consequences of a blowout on platform structure, platform crew, the economy, marine life, and coastal communities were considered beyond the scope of the investigation. The main layout of the investigation is illustrated in Figure 7.2.1.

Hazard Identification

The activities, the technology, and the equipment used for oil drilling and production were studied. As the activities are of different types, a difference in risk level might be anticipated. Therefore, it was found convenient to subdivide the activities into: exploratory drilling – rotation and associated operations (logging, tripping, etc.); production

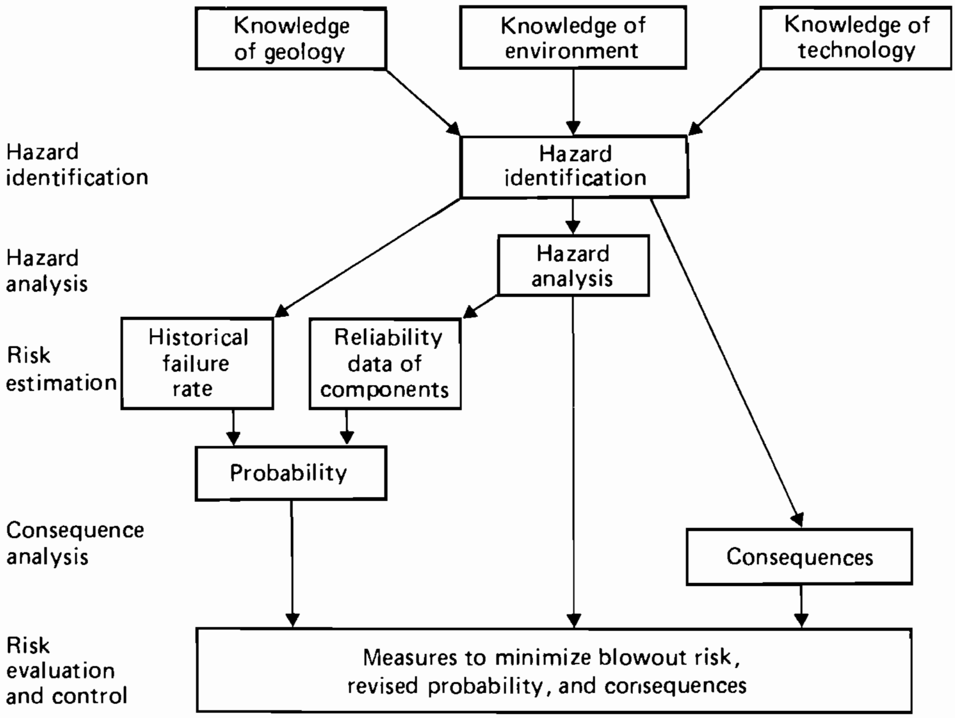


FIGURE 7.2.1 A risk-analysis procedure.

drilling – rotation and associated operations; and production – normal production, workover-wireline (maintenance) and similar operations.

The study included a comparison of present technology and that used at the time of the blowouts included in the historical statistics. Apart from the study of equipment,

TABLE 7.2.1 Risk analysis procedures.

Task	Method	Necessary resources
Hazard identification	Based on observations of similar systems and statistics. Evaluation of the abnormal behavior of a system is based on knowledge of the different elements of that system, in particular analysis of energy and possible release of energy and toxic substances	Knowledge of the system or process under consideration is essential at this stage. If the system is novel, historical data will not be available on the system level. Knowledge of basic physical mechanisms must be utilized
Hazard analysis	By applying methods like fault-tree analysis, failure mode and effect analysis, or other formalized methods. The purpose at this stage is to describe qualitatively the functional relationship between the different elements of a system, and the possible chains of events leading to, or emanating from, a hazardous event	To carry out this stage, there are two types of competence necessary: analytical tools, their possibilities and limitations, and system knowledge. When dealing with large-scale systems, system knowledge is divided between a number of disciplines. In such a case, the "analyst" may provide the coordinating function
Risk estimation	Calculation of probabilities for the different statistical data of accidents in similar or related systems, and reliability data of components used in the system. The availability of data is often less than desired. In such cases estimations can be made by applying knowledge of basic physical phenomena (e.g., corrosion, fatigue) or judgment of groups of people with specific knowledge of the system	The main "source" for this task is "data," and the competence needed is to know where such data can be found, to assess the data as such, to make use of the data in a proper manner, to estimate the confidence of the data themselves and the uncertainties involved in extrapolating the data, and the resulting confidence in the predicted values of risk
Consequence analysis	Prediction of effects involves calculations of data for systems and processes in abnormal states. Examples are the calculation of amounts of flammable and noxious substances released as a result of an incident. Further examples include, the calculation of the spread of such substance on the ground and in the air, effect of fires, explosions, population exposed, etc.	Qualifications cover a range of specialized topics. The most important requirement is knowledge of systems under extreme loads and abnormal behavior, such as the dynamics of structural collapse, the characteristics and effects of shockwaves, exposure to fire, etc.
Risk evaluation and control	This covers a range of methods and procedures. If acceptance criteria are established, comparison of results with the criteria is made. Otherwise, comparison with risk levels in other systems and activities is made. Risk-reducing measures are identified and evaluated	This task requires an analytical approach and involves management decision problems. The decision-maker should take part in the project at this stage, together with the project team

complexity of platform, procedures, safety measures, etc., the technology study also encompassed the qualifications of the crew, the organization and planning of the operations, and the control exercised by the contractor, the licensee, and governmental bodies. The environmental conditions on the Norwegian shelf were also studied and, as the main part of the historical data is from the Gulf of Mexico, a comparison with the environment in that area was made. A similar study and comparison of the geology, as far as was known at this stage, was carried out for the two areas.

On this basis, the hazards involved in offshore oil production were assessed. It was found convenient to distinguish among: platform blowouts, underwater blowouts, cratered blowouts, and subsurface blowouts.

Hazard Analysis

This is a more detailed qualitative analysis for the sequence of events leading up to the blowout. Fault trees may be used to clarify the problem, but hardly for anything else (see Figures 7.2.2–7.2.4). Simple event trees or merely a record of initial events and a record of simultaneous failure of the safety system are more feasible tools in practice.

The initial event may be associated with: geology – shallow gas, deeper high-pressure zones, and lost circulation, etc.; difficult operations – tripping, drilling into nearby wells, and wireline operations, etc.; external causes – dropped objects, driftoff, fire, explosion, etc.

The simultaneous failure may be associated with: failure of equipment – control equipment, safety valves, BOPs, etc.; improper planning – well planning, mud program, casing program, etc.; human errors.

Risk Estimation

A statistical analysis was carried out of all available blowout accident records. Main data sources are the Lloyd's List, which includes worldwide data, and the United States Geological Survey, which publishes comprehensive data for the Gulf of Mexico and the shelves surrounding the USA. This statistical analysis included all relevant information, such as location, platform type, activity phase, initial event, etc. The main data are from the Gulf of Mexico (see Section 7.3). Only a few blowouts have occurred on the Norwegian shelf and could not be made the basis of a statistical analysis. For this reason, the historical data have to be modified to express a realistic future blowout risk on the Norwegian shelf. This is done by studying component reliability. By comparing the reliability inherent in the Norwegian shelf technology, competence and control can be compared to the reliability of the same parameters in the Gulf of Mexico, and the resulting blowout probabilities may be modified. In this modification the geological and the environmental conditions were also considered.

Consequence Analysis

The parameters governing the consequences of a blowout were examined. The types and amounts of materials that can be discharged were studied according to reservoir presure, permeability, gas/oil ratio, production tubing, etc. Possible further consequences such as fires, explosions, oil discharge, etc., were dealt with briefly. Finally, it was assessed how the blowout could be terminated, for example, by bridging, capping, kill mud, relief wells, or other measures. The time necessary to terminate the blowout is decisive in relation to the total discharge.

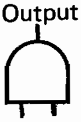
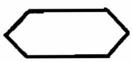
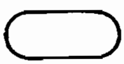
Logic symbol	*Definition of symbol*
	An event, usually a malfunction, that results from one or a combination of other events and is describable in functional terms. Examples are blowouts, kicks, and other generally described occurrences
	A basic event, or lowest identifiable condition or fault. Examples are pore pressures, valve cutout, or valve left open
Output  Input	EITHER–OR: a situation whereby an output will exist if *any* or *all* of the input events are present. An example is a relay valve that will fail if EITHER there is a valve stem seal leak OR the valve spring is hung up OR both events occur
Output  Input	AND: *all* input events must occur to produce the output event
	Transfer symbol – connecting to a more detailed diagram
	CONDITIONAL that another event has occurred or that the named circumstances exist at the time of the event of interest. For example, a high-level sensor failure can only result in an overflow *on condition that* another failure has occurred
	The CONDITIONAL event of interest
	Specific activity involved

FIGURE 7.2.2 Definitions of symbols used in fault-tree diagrams.

Risk Evaluation and Control

Hazard analysis and the component reliability studies also reveal which items are important in blowout risk and which are insignificant. On this basis a decision can be made about the items that should be subjected to special improvement studies and recommendations given on measures to reduce the probability and consequences of blowouts. In general, the important points are to: reduce human errors by increasing automation, improving information systems, etc.; improve the quality of critical mechanical components; improve education of the crew; carry out comprehensive geological investigations; improve control; and plan the system from the outset to simplify blowout control.

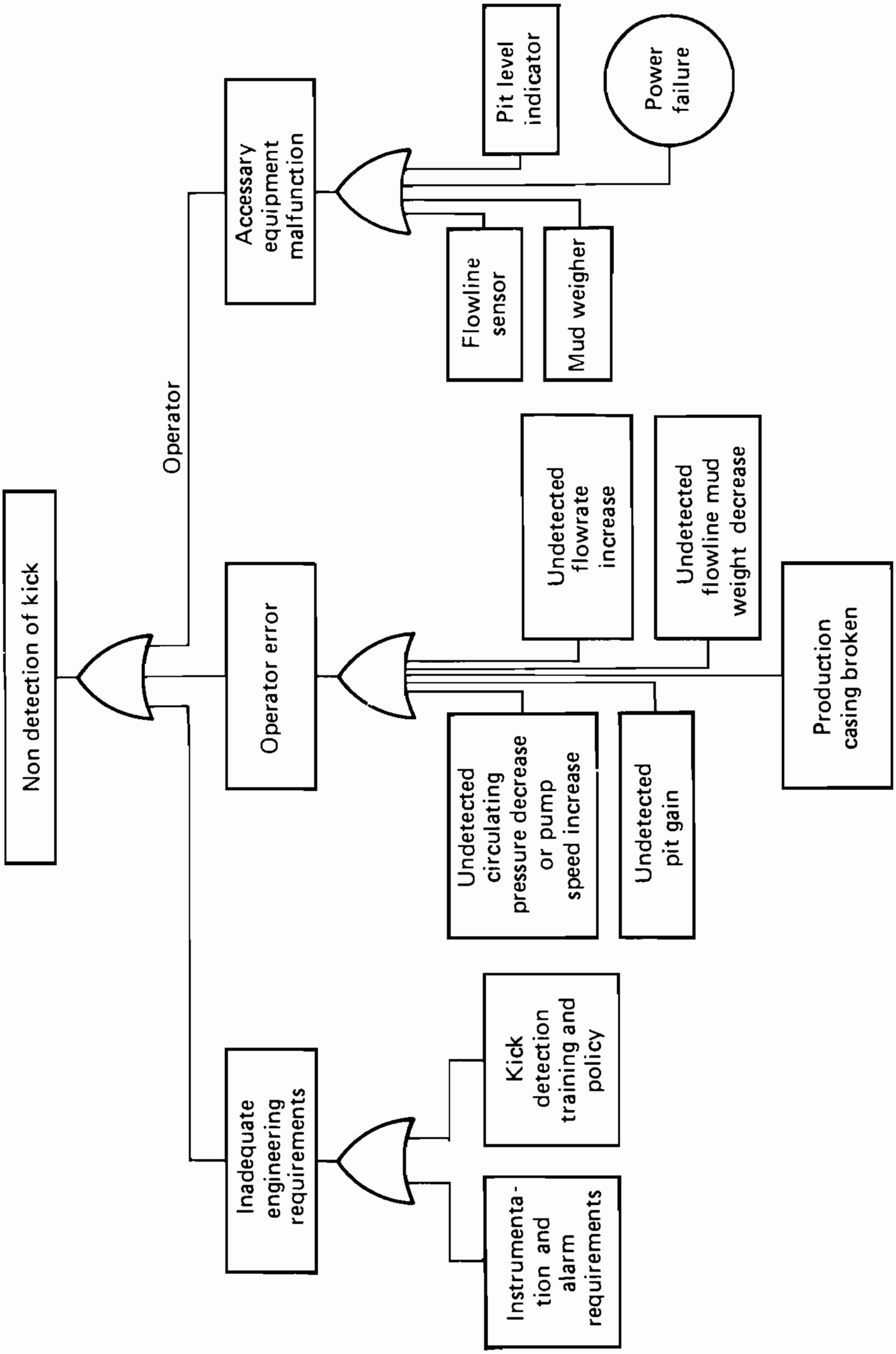


FIGURE 7.2.3 Fault-tree diagram for nondetection of a kick (drilling and completion operations).

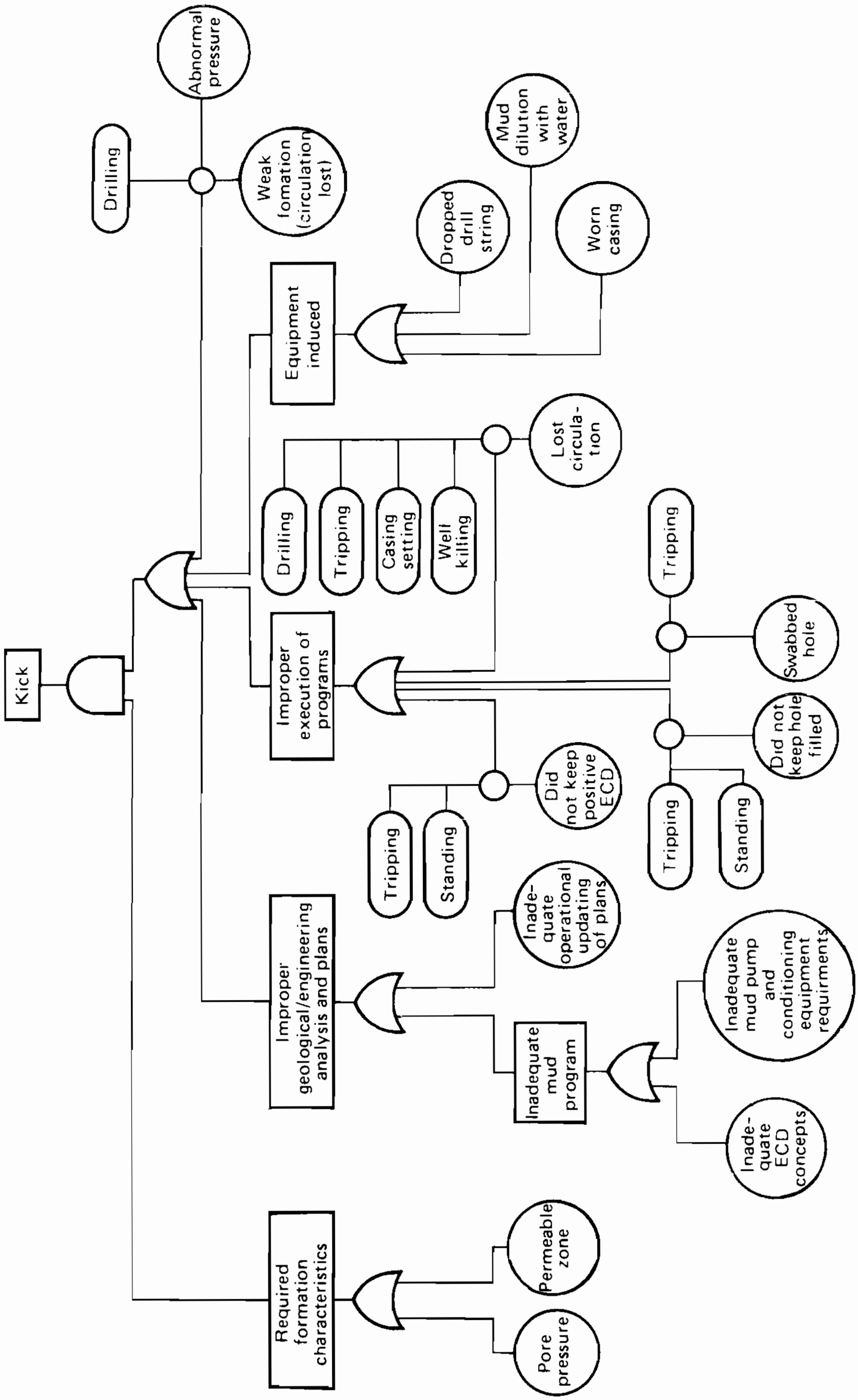


FIGURE 7.2.4 Fault-tree diagram for the development of a kick (drilling and completion operations).

Example of a Consequence Analysis to Assess the Safety of a Subsea Completion System Against External Hazards

General

The following is an extract from a larger study carried out on the safety of subsea completion systems. The analysis was concerned with the following effects of failure of equipment or inadequate operating procedures: hazards to life, pollution hazards, and lost or delayed production. A survey was made of all probable external activities that could damage the "christmas tree" (the set of mechanical valves and casing seats on top of the well which directs the flow of well fluids), together with an estimate of the magnitude of the forces associated with these activities and a prediction of their influence on the christmas tree. Further, an assessment was made of how damage to the christmas tree from these activities might lead to a blowout and how this outcome could be avoided.

Survey of Possible Objects that may Damage the Christmas Tree

The most probable external causes of damage to the christmas tree are illustrated in the fault tree shown in Figure 7.2.5. A fault tree of a blowout caused by external hazard is shown in Figure 7.2.6. When the christmas tree is damaged to the extent that the production string is broken below the master valves, then the only automatic safety feature that can prevent a blowout is the subsurface safety valve. In this event, a blowout occurs when the subsurface safety valve is removed, or if the valve does not close on demand. This is indicated on the left-hand side of the tree.

If the christmas tree is damaged above the manual production valve, the blowout can possibly be stopped by the use of a diver to close this valve. In this case only a limited amount of oil will escape as such an operation takes less than one day. On the other hand, if the wellhead is broken in the 18.75-inch connectors, or the casing below these valves, the blowout could last for an extended period until a relief well is drilled.

If the christmas tree is damaged in such a way that the production casing is broken, but the production string is not, a blowout through the annulus could result if the production packer is damaged. This type of blowout can be stopped, however, in a fairly short time by killing the well through the production string.

Conclusions about Damage Caused by External Means

The marine christmas tree represents an obstacle to fishing in that fishing gear might hook on it; damage can be caused both to the installation and the fishing gear itself. Other objects such as dragging anchors, dropped weights, etc., also represent a hazard to the christmas tree. It is obvious that the present design does not take these aspects into consideration, since it is probable that damage to the christmas tree will lead to a blowout. Consideration should therefore be given to preventive means that will reduce the probability of such hazards. The following recommendations are suggested: prohibit the use of bottom-based fishing gear in areas with underwater installations; mark the positions of underwater installations; shape underwater installations to avoid hooking; and locate underwater installations below the mudline.

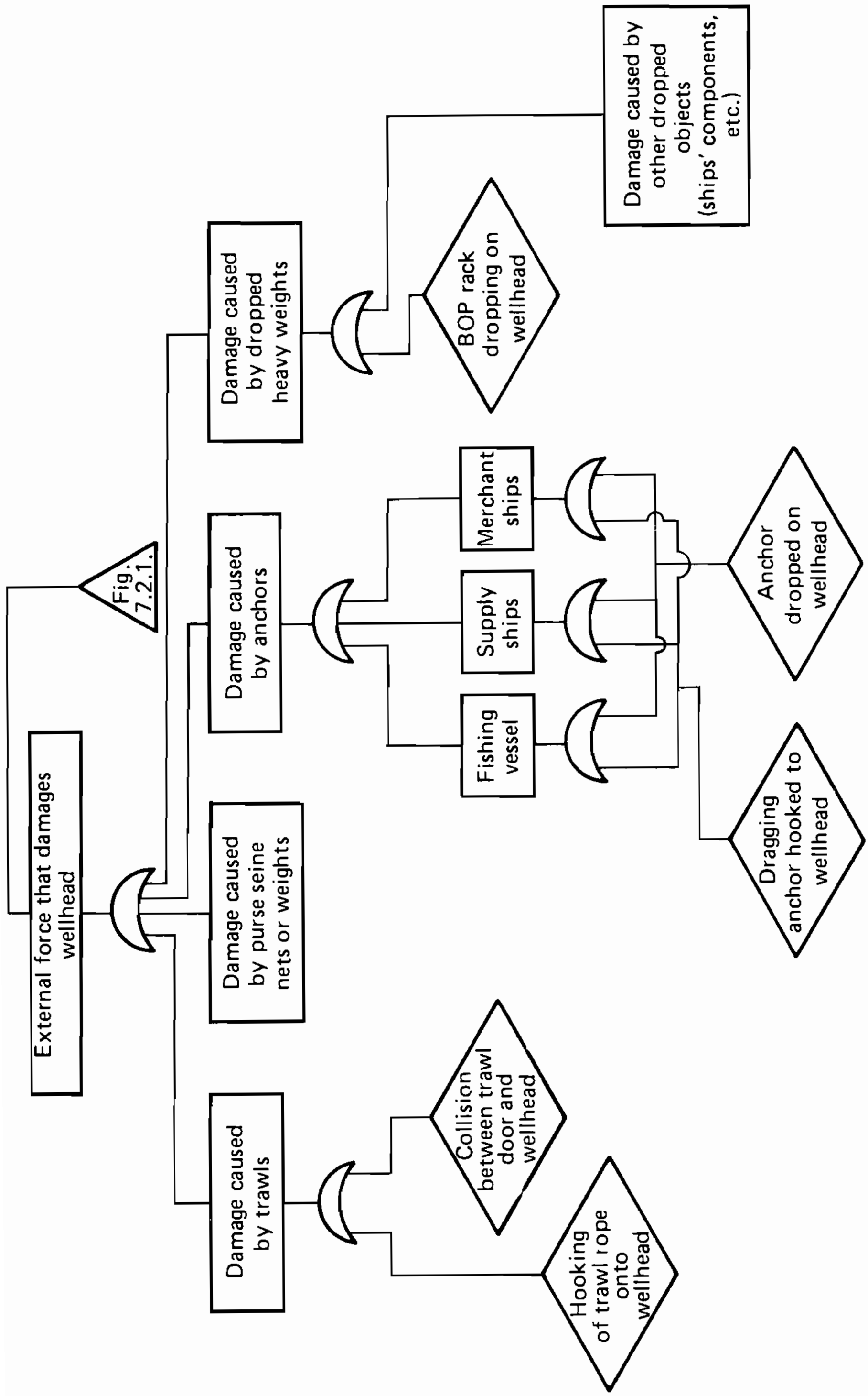


FIGURE 7.2.5 Fault-tree diagram of external hazards that may damage a wellhead.

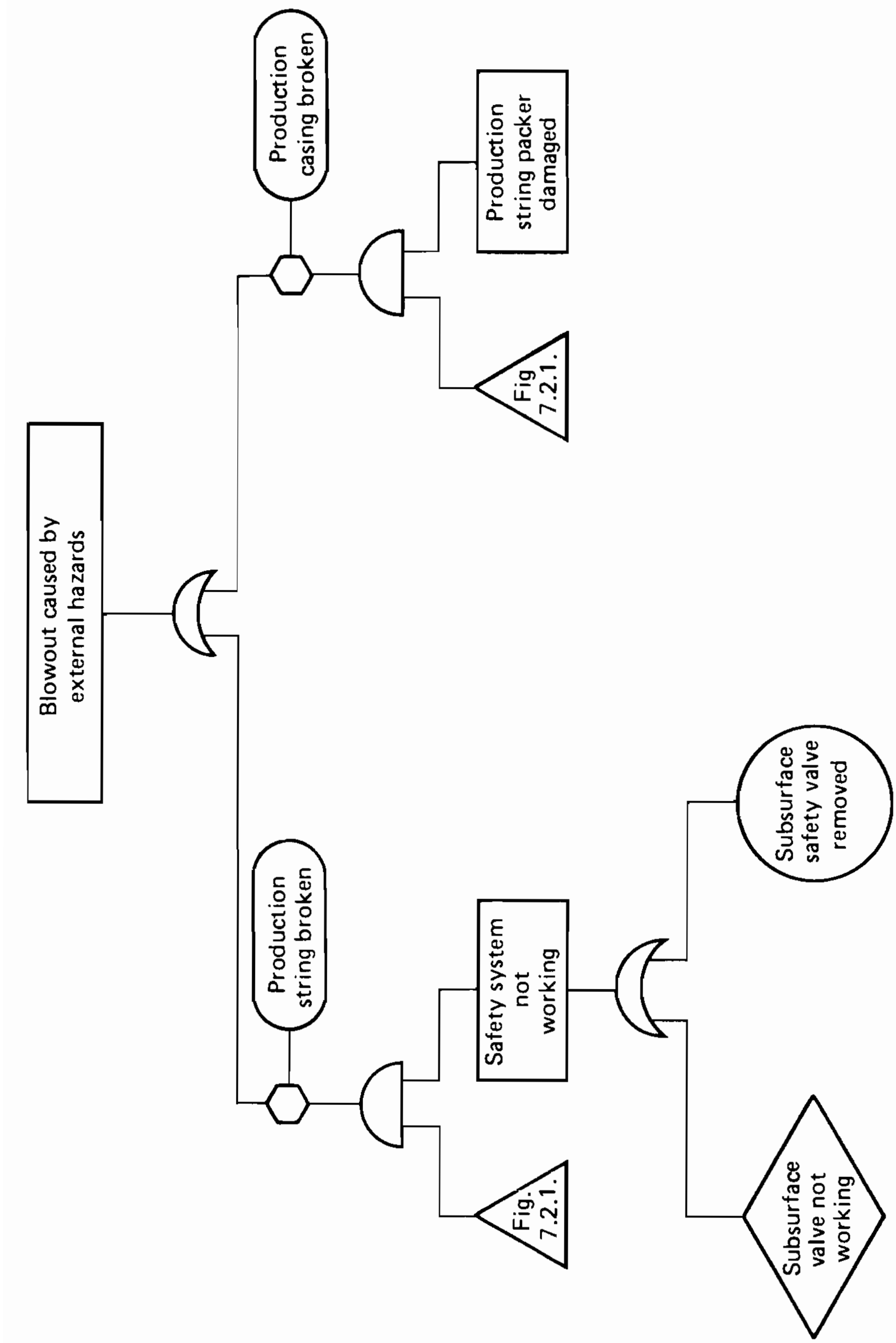


FIGURE 7.2.6 Types of damage caused by external hazards.

7.3 BLOWOUT RISK – GHOST OR REALITY?*

The Ekofisk Bravo platform is blowing wild! This was the alarming message broadcast round the world on April 22, 1977. The populations of all the countries surrounding the North Sea anxiously followed the fighting of the blowout until April 30, when one of the largest oil blowouts ever seen offshore was terminated by a successful capping operation. Fortunately, no lives were lost, no fires occurred, and no shores were polluted. However, public opinion still considers that blowout risk is one of the main hazards to be controlled before further offshore oil development takes place.

To investigate the possible causes of blowouts, Det Norske Veritas carried out a statistical treatment of all available data, covering blowouts all over the world. The data were mainly taken from Lloyd's List, the United States Geological Survey, and the United States Coast Guard. To avoid the introduction of obsolete data, only blowouts occurring in the period 1970–1977 were included. The main emphasis was given to data from the Gulf of Mexico, as these are considered the most reliable. Table 7.3.1 gives the number of blowouts distributed by year and Table 7.3.2 shows the distribution of blowouts over the various phases of activity: about one-third of the blowouts have occurred during production and about two-thirds during drilling. Thus, "workover" and "completion" do not seem to be extraordinarily critical operations.

TABLE 7.3.1 Blowouts in the Gulf of Mexico distributed by year of occurrence.

1970	1971	1972	1973	1974	1975	1976	1977	1970–1977
4	5	6	4	6	6	7	6	44

TABLE 7.3.2 Blowouts in the Gulf of Mexico, distributed by phase of activity, for the period 1970–1977.

Activity	Number of blowouts
Production	10
Production – workover	3
Drilling – rotation	22
Drilling – completion	5
Unknown	4
Total	44

Table 7.3.3 gives the blowouts distributed by degree of structural damage caused. Mobile rigs include drill ships, drill barges, jackups, and semisubmersible platforms. It is difficult to draw clear conclusions from this table, but it seems that most blowouts cause little or no damage, much less a total loss of the platform.

*By Svein Fjeld, Senior Surveyor, Det Norske Veritas, Oslo, Norway.

TABLE 7.3.3 Blowouts in the Gulf of Mexico, distributed by degree of structural damage caused, for the period 1970–1977.

	Total writeoff	Severe damage	Some damage	Minor damage	No damage	Total
Mobile rigs	3	1	1	4	6	15
Other drilling	3	1	–	5	–	9
Production	3	–	1	8	1	13
Unknown	1	–	–	1	2	4
Total	10	2	2	18	9	41

TABLE 7.3.4 Amount of oil spilled during four blowouts in the Gulf of Mexico for the period 1970–1977.

Activity	Amount spilled (tons)
Production	4,500
Production	65
Production – workover	8,000
Production – workover	30

Four out of 44 documented blowouts caused oil spills. Two occurred during production and two during workover on a production platform; in other words, none happened during drilling. Table 7.3.4 shows the amount of oil spilled as a result of these accidents.

Most of the blowouts were terminated by bridging or natural stoppages. Production wells often had to be killed by other methods. Fire was observed at 12 out of the 44 blowouts: six during the drilling phase and six during the production phase. In total, nine deaths were recorded in five accidents. On the basis of estimated numbers for the activity data, the rate of blowouts during the drilling phase is one out of 276 wells, and during production one out of 2,670 wells.

Apart from the oil releases in the Gulf of Mexico and the Ekofisk Bravo incident (22,500 tons), only two significant releases have been encountered worldwide during the period 1970–1978. Both occurred during drilling and the amounts released were: about 3,000 tons of oil per day at the outset for 24 days, when the blowout rate declined; 1,000,000 cubic meters of hydrogen sulfide per day at the outset for 24 days, when the blowout rate also declined.

It was found that one out of every 50 mobile drilling rigs in the USA has had a blowout each year compared to approximately one out of every 140 rigs in the North Sea. It is important to note that this difference is not large enough to conclude that the blowout frequency is significantly higher statistically in the USA compared to the North Sea. The high uncertainty of these figures is due to the low number of blowouts recorded.

Because of the limited amount of data, other methods must be used to estimate the risk of a blowout on the Norwegian shelf. The hazards connected to drilling and production in the Gulf of Mexico and on the Norwegian continental shelf are nearly the same, but several conditions affecting the risk of a blowout are different in the two areas. These conditions can roughly be divided into the following groups: site conditions – geology, physical environment; and technical and organizational conditions – technical equipment, organization and control.

Keeping the technical and organizational conditions constant, the blowout risk would be expected to vary from location to location depending on geology and environment. However, the preventive measures taken by the oil industry have been such that the historical statistics show no such variation. Because compensation is made for difficulties faced, it is impossible to state the risk of blowout on the Norwegian shelf from knowledge of the natural conditions. However, many factors suggest that the consequences of a blowout, in terms of oil spill, on the Norwegian continental shelf would be very different and more extensive than would be the case in the Gulf of Mexico. This implied difference is illustrated by the fact that offshore blowouts in other parts of the world have contributed very little to the total amount of oil released into the marine environment. Other accidents in connection with offshore oil activity, e.g., rupture of oil pipes and damaged stock containers, have caused considerably more serious oil pollution than that experienced from blowouts.

The amounts of oil released will vary with reservoir rock type and depth. During the exploration phase, unforeseen shallow gas pockets can cause a blowout. Pressure and quantity will vary, and it is impossible to anticipate the amounts escaping. The blowouts will probably not last for a long time: after 1–10 days most of the shallow gas will have escaped or the well bore will have been tightened or closed by bridging from the unstable surrounding formations. At worst, the amount of oil release during a blowout in the North Sea will be the same as from an open production well, i.e., 4,000–150,000 tons of oil per day. The probability of such an accident is very low. In fact, world statistics (offshore and onshore) indicate that only about one-tenth of all blowouts involve any oil whatsoever, and only one-hundredth include significant amounts of oil. The Maersk Explorer blowout, which blew water and gas for a few days before termination by bridging, is fairly typical of a blowout during exploratory drilling.

During the production phase, blowouts can occur at two stages : in an open well, that is when the well is out of operation, for example, during change of damaged tubing; and in a completed well in which all valves are installed, the flow diameter is smaller and the flow resistance higher compared to an open well. Thus the amount blowing in the latter case is smaller compared to an open well. Table 7.3.5 gives estimated maximum amounts escaping during hypothetical blowouts in the Statfjord and Ekofisk fields for the actual pipe diameters used in open and completed wells.

It is impossible to estimate the productivity of reservoirs north of latitude 62° N, but possible commercial fields must be of the order of magnitude of the Ekofisk field. The figures for the North Sea may thus be used an an illustration for future fields developed. The rate of production in the Gulf of Mexico varies from well to well, but, since small fields are also commercial, a typical maximum for escape would be approximately 200–400 tons of oil per day.

If the blowout does not terminate by bridging, the well may in certain cases be capped by mechanical equipment. If this operation is successful, the blowout will probably last for a period of the order of days or weeks. If it is not possible to terminate the blowout in other ways, relief wells have to be drilled. Terminating a blowout in this way can take up to five months in the Gulf of Mexico. Improved technology and well-established

TABLE 7.3.5 Maximum amounts of oil escaping during hypothetical blowouts in the Statfjord and Ekofisk fields.

Field	Well type	Outer pipe diameter (inch)	Oil escaping (tons/day)
Statfjord	Open	9.125	15,000
	Completed	7.0	10,000
Ekofisk	Open	7.0	10,000
	Completed	4.5	4,000

emergency plans may render the drilling of relief wells possible within 2–4 months in the Norwegian continental shelf. Depending on the type of reservoir, the oil and gas flow may, after some time, change to a flow of water (water-coning).

The historical data indicate that about 10% of blowouts in the Gulf of Mexico have caused loss of human life and that about 30% ignited. On the Norwegian shelf there is greater probability that a blowout during exploration drilling will be of the subsurface type, which has less chance of igniting. Consequently, the risk of fire may be considered lower on the Norwegian shelf.

The platforms used for exploration and production on the Norwegian continental shelf are, and will continue to be, large and expensive with many persons on board. Improved reliability and built-in safety must therefore be economically favorable. Thus, both the public and the oil companies demand a technological and supervision system that gives lower blowout probability compared to historical statistics.

On the basis of calculated probabilities, corrected for differences in technology, supervision (both public authority and company), training, geology, and physical environment between the two areas, an estimate has been made of the possible reductions in blowout probability on the Norwegian continental shelf compared to the Gulf of Mexico. Risk analysis shows that the weakest points are situations where the crew must make their own decisions when unexpected reservoir conditions occur. Mechanical equipment is more reliable than human reactions. A fault-tree analysis on drilling from ships in Canadian waters found the malfunctions to be distributed as follows: equipment malfunction – 5.8%; improper planning – 5.0%; operation failure – 72.6%; failure due to external conditions – 6.4%; and drill-ship failure – 10.2%.

When the blowout is just beginning and has to be fought, there will often be a high noise level, strong vibrations, a high rate of mud return, and eventually escaping gas and oil. The drill crew is then exposed to stress, which increases the risk of its taking the wrong actions. Often blowouts will occur when the crew is not well prepared and when superior staff, without fixed working hours, is not present. More than 50% of all blowouts take place between midnight and 08.00 hours, and especially between 02.00 and 03.00 hours. Also, some mechanical components have rather low reliability, e.g., downhole safety valves. The reliability of critical components, however, is constantly improving, and in certain cases it is possible to use two units to improve safety.

During exploration drilling the following factors are of the greatest importance in determining blowout probability: shallow and deep overpressure zones, procedures, operator qualifications, and control. Proper preliminary investigations and supervision of well conditions have reduced the probability of a blowout on the Norwegian continental shelf compared to historical data for the Gulf of Mexico.

For blowouts during exploration drilling, the reservoir conditions will have a great influence on the consequences, measured by the amount of oil spilled. By developing new equipment that may terminate the blowout more quickly, it is hoped that the consequences on the Norwegian continental shelf may be reduced.

The environmental conditions on the Norwegian continental shelf are more hostile than in the Gulf of Mexico; however, this difference has relatively little influence on the probability of a blowout and such factors as supervision, well-pressure control, rig design, and the design of equipment for rough-weather conditions. Each of these factors could potentially compensate for the more adverse environmental conditions.

For blowouts during rotation and operation in the production phase, the factors of reservoir conditions, qualifications, procedures, and control are very important. By proper planning, preliminary investigations, and supervision, it ought to be possible to lower the probability of blowout in the Norwegian continental shelf compared to the Gulf of Mexico. During production, equipment deterioration (for example, from the effects of sand) represents a hazard.

Thus, environmental conditions do not seriously affect the probability of a blowout during the production phase. As for exploration drilling, the rougher weather conditions on the Norwegian continental shelf compared to the Gulf of Mexico can be taken into account.

Some of the measures noted above for reducing blowout risk have already been introduced in the North Sea. On implementing further measures it should be possible to reduce the probability of a blowout even further. On the basis of published data, a reduction to one-tenth of previous world levels seems realistic. The probability of simultaneous malfunction of safety equipment should also be reduced correspondingly, which is important because the overall probability of blowout can, in principle, be expressed as the product of these two individual probabilities. During production it should also be possible to reduce the possibility of a blowout to an even lower figure than that for the drilling phase. As the equipment needed will be expensive to develop and produce, thorough cost estimates are necessary to decide which efforts are to be selected for attaining a real improvement in safety. An effective reduction of the probability of a blowout in the two phases, however, requires thorough studies of how the new equipment will function as a part of the system as a whole.

No conclusive answer to the question heading this section can be given. The possibility of blowouts on the Norwegian shelf cannot be excluded, but the probability has been much reduced compared to historical data from the Gulf of Mexico. Because of continuously improved technology, the probability may be expected to decrease even further in the future.

If a blowout occurs during exploration drilling, it is very unlikely to result in major damage such as loss of life or significant pollution. For a blowout during the production phase, the amount of pollution might be larger, but by appropriate measures it may be kept at an acceptable level.

7.4 OFFSHORE INDUSTRY NEEDS SAFE OPERATORS IN SAFETY-CONSCIOUS ORGANIZATIONS*

The main safety problem offshore is that one is confronted with a very complicated technical and social system. After accidents have occurred, public opinion creates pressure for something to be done about safety. In such situations, it is easy to take a specific problem, reduce its particular risk, and then believe that the causative pattern leading to the accident has been broken. It is probably also thought that total safety has increased.

It is natural to look at concrete technical problems since these are very easy to recognize: a defective engine, broken conductors, valve failure, defective automation systems, and so on. By developing reliable technical components, the risk that a technical failure can develop into a technical breakdown or catastrophe is diminished.

Seen in the light of pure logic, safety technology will yield safer places of work. By continually increasing and developing this technology, the risk from technical failures or defects will continuously diminish. But in this context -- as elsewhere – technical reliability can become so good that personal vigilance and judgment deteriorate. It is possible to rely so much on technical systems that the personal qualities and knowledge necessary to detect and control an unforeseen situation where the technical system breaks down are entirely lacking.

Statistics and reports from the more serious accidents offshore show that "human failure" or lack of knowledge and experience are the main causes of accidents. This aspect is, of course, only part of the problem, but it serves to illustrate that, in the final analysis, safety problems are caused by human failings. It is difficult to give general recommendations on the human aspects of safety, because people are so different in ability, precision, reaction, responsibility, and other qualities.

These difficulties make the study of human failure less exact and complete than studies of technical failures. Even so, something has been learned through systematic studies of human behavior in different situations. The most important is perhaps that human failure is not subject to simple cause-and-effect relationships. In a hazardous situation many complicated and interactive events canbe the consequences of a simple random pattern of events called causes. To derive one simple cause—effect relationship from this complicated pattern might well hide what actually happened in an accident. In such ill-defined situations it is not easy to know what to do. What is usually done, or rather recommended, is to emphasize the development of safety routines and drills, to promote selection and education, and, of course, to define responsibilities. This emphasis may increase vigilance and some of the personal qualities needed to cope with an abnormal situation; but, at the same time, it may alter the focus of attention and safety research away from the technical conditions themselves, which might then change by degrees without adequate safety measures until a point is reached where there is an imbalance between the technology utilized and the human resources so intimately linked with it.

For instance, the platform installations today are so large and the technical and physical chain reactions in the process plants so fast that the development of lifesaving equipment and contingency plans have not kept pace. This is a general problem also encountered in the shipping industry. The largest oil tankers are so immense that

*By Carsten Bøe, Project Leader, System for a Safe Ship, Norwegian Council for Scientific and Industrial Research.

fresh-air plant is of insufficient capacity to allow personnel to rescue a crew member who has collapsed in a tank from lack of oxygen. In such instances, vigilance, a sense of responsibility, and experience are not enough to deal with the situation.

It follows that the complicated technical and social systems that affect the safety problem must be tackled at two levels. The first level is organization. An organization with a safety-conscious climate has an ability for internal self-regulation instead of being dependent on coordination and control from outside. This ability has the ultimate consequence that those concerned with safety, that is, platform personnel, must work always with safety in mind and be aware of their own influence and responsibilities in this respect. In a safety-conscious organization, safety is part of the daily routine and the implications of every technical development that entails changes in the organization must be translated into social terms. This process ensures that those who are affected by the changes become involved with, take responsibility for, and learn from the safety measures demanded by such changes. These are basic principles for an organization with a safety-conscious climate. The platform is viewed as a technical system, a place of work, and an environment in which to develop and increase safety on a full-time basis; safety cannot be forgotten during spare-time periods, or at other times of recreation and relaxation. In consequence, overall safety impinges on the whole social climate of the platform and on the social and psychological resources that can be built and maintained there.

The second level is the problem of creating a safe operator. This is easier to define, the objectives being to minimize the probability of failure and to maximize the probability of correction when an error has occurred. There are two approaches to achieve these ends. The first reasons that no human being is perfect, many human actions will be imperfect, and it is human to fail. Hence, human error is anticipated.

The second approach is ergonomic: human failures are caused by lack of adaptation between the abilities of the operator and the demands of the work situation. Human failure will occur when the relation between ability and demand is out of balance. The built-in potential for failure in humans does not occur until this imbalance catalyzes the reaction that leads to potential failure. This type of thinking has the advantage that, at least in theory, human failures can be completely eliminated by simply eliminating the catalyst. Current work on human failure and human engineering is performed at this level. The goal is to create a safe operator or man–machine interface where human errors can be tolerated. Much has been learned in this field, but too little of the knowledge gained has been put into practice.

The really difficult safety problem is at the organizational level. The report on the Bravo blowout highlighted this aspect. It is very important to solve safety problems at the organizational level, because a safety-conscious climate in an organization defines the boundary conditions for a safe operator.

But what is the situation today? The pattern of development is often like this: technological resources are created and developed for a specific technical environment, and technical and economic criteria are used as the basis for selecting alternatives. The social system is only considered as an afterthought. When everything goes well, it is of little interest to evaluate whether technical development is too fast for the social organization to stabilize itself under the new conditions. However, when a serious accident occurs, the human factor becomes predominant. The low priority of social criteria within the organization is then pointed out, and great efforts are made to straighten things out.

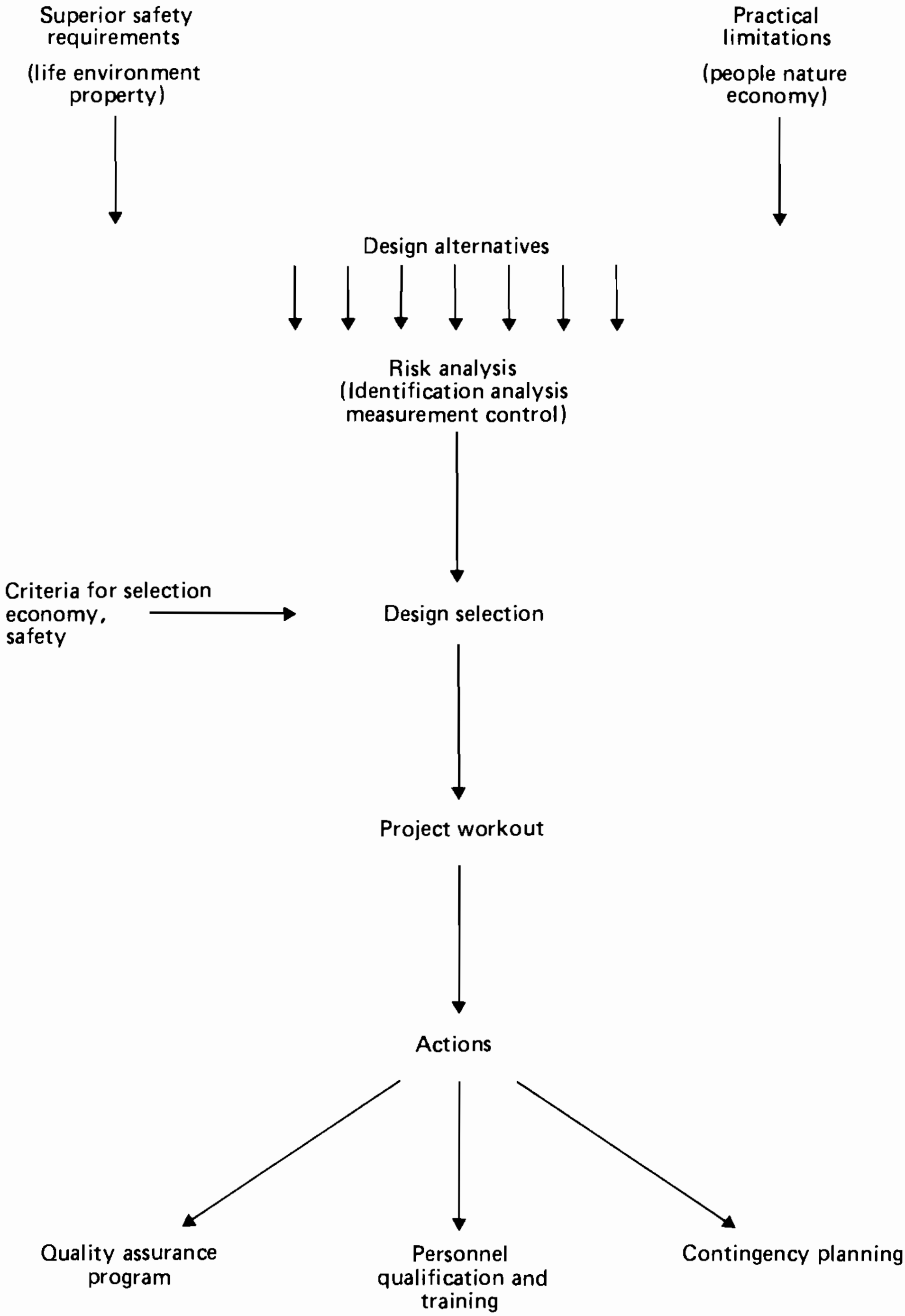


FIGURE 7.4.1 An approach to safety.

This division of interests between onesided technical and onesided pyschosocial problems results from several causes. However, in the present context it is very important to understand the sequence itself. First, the technical system evolves at such a rate that the associated social organization is not given time to stabilize itself. Then the imbalance between the technical and social systems is pointed out and cited to be the cause of any accidents. The specific reasons quoted may be lack of knowledge about the technology employed, lack of experience, lack of responsibility, and so on. In the offshore oil industry this situation will not improve as long as safety development remains only a minor factor in the specialized technical environment.

Offshore safety must become part of long-term development work whose purpose is to integrate technical and psychosocial measures. An overview of this problem is illustrated in Figure 7.4.1. It is not enough to be simply aware of the problem. Adequate research funds must be made available and the repercussions of project organization, methods, goals, activities, and working partners on the problem must be continually reviewed and research restructured to take account of such factors. It is necessary to take an overall point of view and a long-term perspective based on this principle: "safety problems must be treated as sociotechnical problems in that technical and social aspects of the working environment are not isolated from each other." In offshore safety work this principle means that technical improvement of safety cannot be accepted as a contribution to total safety before the associated social and psychological consequences are evaluated. Changes in the content of the work may have organizational and psychological effects that may eventually reduce safety.

In this brief section, the emphasis has been put on the importance of creating a safety-conscious organization. This is the cornerstone of safety work offshore. Also, a safety-conscious organization defines the boundary conditions for a safe operator. Compared to human engineering and ergonomics, very little work has been done on this subject, although much work is needed in this field, and needed very soon. International cooperation on research projects would give a much-needed impetus to this important work.

Acknowledgments

The author is indebted to his fellow scientists in the Norwegian System for a Safe Ship research program for help and comments.

7.5 A REGULATORY APPROACH TO BLOWOUT PREVENTION*

Prevention Philosophy

Regulations governing offshore oil development operations should be firmly based on the prevention of blowouts and other accidents, rather than on measures designed to

*Based on comments made during the Workshop by Dag Meier-Hansen, Director, Inspection and Control, Norwegian Petroleum Directorate. Since Mr. Meier-Hansen did not submit a formal paper, we present here an outline of his remarks.

limit or handle the effects of such accidents. In addition, the question "How safe is safe enough?" must be considered: this issue can be handled by political assessments or by attempts to quantify the risk inherent in a given operation.

The position in Norway at the time of writing is roughly as follows. The government is answerable to parliament for its actions and decisions through two ministers: the Minister for Oil and Energy is responsible for operations and the Minister for Labor is responsible for safety matters. Relatively few detailed regulations are yet in force, and no such regulations existed prior to 1969. Regulatory efforts to date have concentrated on drilling operations. Nine different organizations inspect proposed drilling operations whenever applications are made for government approval of drilling programs.

Problems in Prevention

On moving from the philosophical to the practical details of blowout prevention, a number of problems must be faced and decisions made. These may be categorized as follows. How should the government, or other appropriate licensing authority, choose a prospective oil operator or company from among the many applicants? How should the activities of contractors and subcontractors be regulated, and how best should individual platforms and their operations be inspected and controlled? It is obvious that an operator must bear a good deal of responsibility for his own actions but at the same time it is necessary that a certain level of political confidence in the operation be maintained (perhaps based on visible governmental controls): how should a satisfactory compromise be arrived at? Sometimes it is possible to develop safer designs and use these to cut down safety distances around various components on a platform. More generally, given the conflicting needs of numerous different operations on the same platform, overall risk must be minimized. How best should these two aims, the substitution of safer design for safety distance and the minimizing of overall risk be achieved? Turning to safety and accident-prevention regulations, what is the best time to apply such regulations and what degree of detail is most appropriate for each regulation?

Recommendations

Those concerned with the safe operation of offshore oil and gas development can learn a great deal from the experience and operating procedures of land-based organizations such as the oil-refining and petrochemical industries. Discussions with prospective operators should start at an earlier stage and more attempts should be made to directly motivate operators to be safety conscious. The discretionary powers of certifying authorities should be strengthened and a more rigorous inspection system should be designed and implemented. Some difficulties have been experienced to date in getting oil companies to accept risk analysis; also, problems in starting a follow-up reporting system for near-accidents have been encountered, but it is felt that both this and the risk-analytic approach are worthy of further efforts. Finally, after five years of requests to the oil companies for more information on design concepts and risks, and very little response, Statoil has now begun its own risk analyses.

7.6 LEGISLATION FOR OFFSHORE FACILITIES IN THE MARINE ENVIRONMENT*

Historical Introduction

Large-scale exploration for oil and gas in and around the United Kingdom has only taken place during the last 10–15 years. However, there were small-scale operations very much earlier, and some of the legislation dates back to these earlier activities. In Shropshire tar springs were used for medicinal purposes in medieval times, while there were reports, in the seventeenth century, that gas was escaping from a spring near Wigan in Lancashire. In 1885 natural gas was used for lighting the railway station at Heathfield in Sussex.

The UK government first sponsored the search for petroleum during the First World War when submarine attacks threatened overseas supplies. This led to the first legislation governing petroleum, the Petroleum (Production) Act of 1918 [1], after which oil was found in small quantities at Hardstoft in Derbyshire. In 1934 a new act was passed which vested in the Crown the ownership of all natural petroleum not then discovered. Subsequently, oil was discovered in 1940 at Eakring in Nottinghamshire, which made a small but useful contribution to oil supplies during the Second World War.

In 1958 the first United Nations Conference on the Law of the Sea was held and the ensuing Convention on the Continental Shelf [2] agreed that coastal states were entitled to exercise sovereign rights over the continental shelf for the purpose of exploring it and exploiting its natural resources. At that time the continental shelf was commonly taken to refer to the seabed and subsoil outside territorial waters to a depth of 200 meters. This has since been revised and a further revision is currently under consideration by the United Nations Law of the Sea Conference. The UK duly ratified the 1958 convention and in 1964 passed the Continental Shelf Act [3], which applied the provisions of the Petroleum (Production) Act of 1934 [4] to the UK continental shelf.

Following the passing of this act, regulations governing the continental shelf and territorial sea were made in May 1964, and later the same year the first licences were issued. The first offshore gas field (West Sole) was discovered in 1965 and gas was first brought to shore in 1967. At the time of writing, natural gas supplies met nearly all the gas needs of the UK and satisfied about 17% of the primary energy requirement (25% of useful heat consumption). The first commercial oil field (Montrose) was discovered in 1969 and commenced production in June 1976. The first oil production, however, was from the Argyll field in June 1975. At the time of writing, nine oil fields were in production and were contributing about three-quarters of the primary oil demand in the UK, and it was anticipated that by about 1979 or 1980 the UK would be self-sufficient in both oil and natural gas.

The legislation and regulations that have been promulgated to control these activities can be grouped into measures for ensuring the safety of offshore structures and those

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working on or near them; and measures to protect the interests of other users of the sea – shipping, fishing, and coastal interests.

Safety of Offshore Installations

Safe Conduct of Operations

Safety of workers has always been a major concern of UK governments, and the first Continental Shelf Petroleum Production Regulations issued in 1964 [5] contained (amongst others) clauses requiring licensees to: obtain the consent of the minister for the drilling and abandonment of wells; "execute all operations in or in connection with the licensed area in a proper workman-like manner in accordance with methods and practice customarily used in good oil field practice"; "comply with any instructions from time to time given by the Minister in writing for securing the safety, health and welfare for persons employed in or about the licensed area."

These clauses were designed to minimize the risks of a blowout that could cause loss of life, to reduce the risks of extensive pollution, and to promote good operating practices, thereby improving the safety of workers and reducing accidental pollution. Several instructions were issued, one of which required licensees to conform to the Institute of Petroleum's Code of Practice for Drilling and Production in Marine Areas [6]. Enforcement of these requirements was carried out by inspectors of the then Ministry of Power.

Mineral Workings (Offshore Installations) Act 1971 [7]

On December 27, 1965 the jackup rig "Sea Gem" collapsed with 32 men on board and 13 lives were lost. A formal enquiry was held, which concluded that the existing provisions for safety did not cover this type of disaster adequately and recommended that a statutory code, backed by credible sanctions, should be introduced and that an individual on each installation should be responsible for safety. Following these recommendations, the Mineral Workings (Offshore Installations) Act was passed, coming into force in July 1971. This was an act to "provide for the safety, health and welfare of persons on installations concerned with the underwater exploitation and exploration of mineral resources in the waters in or surrounding the UK, and generally for the safety of such installations and prevention of accidents on or near them."

An "installation," under the terms of this act, includes both mobile and fixed installations concerned with the exploration for or production of oil or gas. It includes therefore drillships, jackups, and semisubmersibles, as well as fixed platforms (both steel and concrete). Any new types of installation that may be developed for this sort of work in the future, such as tethered buoyant platforms, etc., will also be covered by this act.

The act itself requires installations used on the UK continental shelf to be registered and to have a valid certificate of fitness, and it makes provisions for regulations to be issued governing these matters. Clauses 4 and 5 of the act require managers to be appointed who shall have the general responsibility for all matters affecting safety, health, or welfare of the persons employed on the installation and, where necessary from a safety point of view, for the maintenance of order and discipline on it. Other clauses enable the

Secretary of State to make further regulations about the safety of the installations and the people employed on them.

It is not possible in this brief section to discuss all the regulations that have been made, but mention must be made of the Inspectors and Casualties Regulations 1973 [8], the Construction and Survey Regulations 1974 [9], the Operational Safety, Health and Welfare Regulations 1976 [10], the Emergency Procedures Regulations 1976 [11], the Life-saving Appliances Regulations 1977 [12], and the Fire-fighting Equipment Regulations 1978 [13].

Inspectors and Casualties Regulations

These were among the first regulations to be issued and they make provision for the inspection of offshore installations by inspectors appointed by the Secretary of State, and for reporting casualties and other accidents. They detail the powers given to inspectors and require owners of installations and others to assist the inspectors in carrying out their duties. All installations on the UK shelf are inspected at intervals of approximately 3–4 months, and all fatal accidents and serious occurrences are investigated by inspectors of the Petroleum Engineering Directorate of the Department of Energy.

Construction and Survey Regulations

When the Construction and Survey Regulations were being prepared, an advisory committee composed of representatives of various government departments and research institutes with expertise in problems related to offshore engineering was appointed to advise on their technical content. This committee came to the conclusion that in many areas there was insufficient knowledge to enable detailed regulations to be made. Also, technology was, and still is, evolving very rapidly and detailed regulations based on inadequate knowledge would badly inhibit offshore development without adding to safety.

Consequently, the regulations were broadly framed and were supplemented by Guidance Notes [14, 15], which are an aid to interpreting the regulations in the light of current knowledge. At the same time, research was instituted whenever needed. As the results of this research work became available, and, in the light of the operational experience in the UK continental shelf (and elsewhere in the world), the Guidance Notes have recently been revised and reissued.

Under these regulations no fixed or mobile installation may be used during the exploration, drilling, or production stages of mineral operations on the UK continental shelf unless it has a valid Certificate of Fitness stating that it is suitable for the purpose for which it is intended and for the environment at the place where it is to be used. Certificates of Fitness are issued by one of the Certifying Authorities appointed by the Secretary of State. Initially, there were five such Certifying Authorities, namely, the internationally recognized ship classification societies: Lloyd's Register of Shipping, London; Germanischer Lloyd of West Germany; American Bureau of Shipping of the USA; Bureau Veritas of France; and Det Norske Veritas of Norway. A sixth body has since been added to the list: Halcrow Ewbank and Associates Certification Group of the UK.

Before issuing a Certificate of Fitness, a Certifying Authority is required to carry out an independent evaluation of the design of the installation to ensure that the design is suitable for the installation to fulfill its intended function in the area for which it is intended. Furthermore, the Certifying Authority has to carry out surveys of the installation to ensure that the installation continues to be fit for use.

It should be clear therefore, that the Certifying Authorities play a vital role in the safety of offshore installations, not only during the design and construction period, but also throughout the life of the installation. They are concerned not only with the strength and stability of the primary structure itself but also with the secondary structures and the equipment.

Guidance Notes

At a very early stage it was decided that the routine work of certification, design assessment, supervision, and periodic survey should be undertaken not by any government organization, but by suitable agents appointed for the purpose. At that time the principal ship-classification societies mentioned above were identified as potential candidates and preliminary, informal discussions were initiated with them.

After the nature of the task had been explained the five societies stated they had the competence, capacity, and organization to do the work, and satisfied the department that this was so. But they maintained that the department should stipulate the standards to be worked to, pointing out that, in the shipping world and in the construction industry, common standards and sound practices had been developed over a long period of time, whereas no such equivalents existed offshore. The department accepted this view and in 1974 produced the Green Book, Guidance on the Design and Construction of Offshore Installations [14].

The Green Book was put together under pressure. Offshore activity was then increasing rapidly; all existing installations in the UK sector were awaiting certification, and some, at least, were already known to be dangerously below standard; owners with new construction on the drawing board or on a building site were pressing for decisions on numerous points of design and construction. In these circumstances, "something workable now" was considered preferable to "something better too late"; priority was given to speed of publication and a loose-leaf form was adopted with a view to the ready incorporation of additions and amendments.

The Construction and Survey Regulations and the Green Book were both published at the beginning of 1974 and during the next few years all available resources were concentrated on ensuring the effective operation of the certification scheme. Little capacity could be spared to implement the amendment scheme as originally planned, although a wealth of experience was gained, supplemented by valuable criticism and comment from numerous sources. By 1976 the department realized that amendment would no longer suffice, and a firm of consulting engineers was retained to edit a completely new edition of the Green Book, taking into account, in collaboration with the department, the experience gained, the comments received, and technical developments that had taken place since the beginning of 1974. The end result is the publication: Offshore Installations – Guidance on Design and Construction – 1977 [15], the Blue Book.

Like the earlier edition, the primary purpose of this book is to provide experienced engineers with a guide to standards of design and construction that will comply with the statutory obligations set out in the Offshore Installations (Construction and Survey) Regulations of 1974 [9]. It is not intended to be either a design manual or a code of practice, although, inevitably, there is some overlap into both these areas. Technical data are included where the material is not generally available or not yet well known, but as a general rule reference is made only to established relevant sources.

Operational Safety, Health, and Welfare Regulations

These regulations represent one of the most important sets to be made under the 1971 Act [7], and lay down standards of safety in an area that is the source of by far the majority of accidents on offshore installations.

In particular, the regulations lay duties and obligations on concession owners, owners and managers of offshore installations, employers, and employees to ensure that the provisions of the regulations are complied with, and generally to ensure that operations on and near installations are carried out in a safe manner. They promote the use of safe practices widely recognized as being essential to safety in any industrial environment, and, in addition, provisions are laid down for certain procedures unique to offshore installations. These include: the appointment of competent persons to be responsible for given equipment or operations; the preparation of written instructions by owners of installations covering all aspects of the safe operation of the installation; a "permits to work" system for certain particularly dangerous operations which could give rise to fire or explosion; and provision of a proper maintenance schedule for all equipment, effective guarding of equipment, and regular examination of all lifting appliances. The regulations complement the Construction and Survey Regulations and together they form the basic framework of safety provisions for operations on offshore installations envisaged at the time of preparation of the 1971 Act [7].

Emergency Procedures Regulations [11]

These regulations require written procedures to be established on every installation to cover any of the emergencies that may occur, such as fire, blowout, collision, structural failure, etc. All persons on an installation have to know what their duties are in the case of such emergencies and regular practice drills have to be held. The regulations also require that there shall be a standby vessel within five nautical miles of every installation that is manned. This vessel has to be capable of taking on board everybody from an installation and has to be equipped to provide first-aid treatment.

Fire-fighting Equipment Regulations

These regulations cover such matters as the provision of automatic fire-detection systems, gas detectors, etc., and the provision of various types of fire-fighting equipment.

The Role of the Health and Safety Commission

In 1976 it was decided that the responsibility for the occupational safety of workers on offshore oil and gas installations should be transferred to the Health and Safety Commission so as to afford them the same protection given to workers onshore. This was brought into effect on September 1, 1977 by means of an Order in Council [16] extending certain parts of the Health and Safety at Work Act [17] to offshore sites. This means that the policy for occupational safety matters on offshore installations is now the responsibility of the Health and Safety Commission and its Executive and theirs will be the responsibility for producing any further regulations concerning such matters. However, the responsibility for the safety of the structure of the installations themselves and also the control of operation so as to minimize the risks of blowouts, which are inherent in the drilling for oil and gas, remains with the Department of Energy.

The enforcement of all regulations on the offshore installations remains with the Inspectorate of the Department of Energy acting, where appropriate, as agents of the

Health and Safety Executive. The enforcement has been left in the hands of a single Inspectorate so as to leave the operators in no doubt for whom they are responsible in safety matters, and who to notify in case of accidents, etc.

General Policy on Offshore Safety Summarized

The UK government's approach to the safe design and safe operation of equipment used in the exploration and production of petroleum offshore is essentially flexible and takes into account the rapidly developing technology employed in an environment as harsh as that experienced anywhere in the world. Extensive use is made of established codes of practice wherever they exist, but it is recognized that in many cases they may need modification to meet the conditions peculiar to offshore sites, and in particular the necessity to conserve space as far as possible. Emphasis is placed on the responsibility of the owners and the operators of offshore installations and equipment for the safety of these and the people working on them. The government defines the broad principles that must be adopted and monitors the conduct of operations to satisfy itself that these principles are followed. Emphasis is placed on the need for the man on the spot to be aware of the hazards under which he is operating and his responsibility for the safety of both himself and others on the installation.

Protection of Other Maritime Interests

At every stage in the development of an oilfield, from exploration through to production there is potential for conflict with other maritime interests. The following are some examples of the regulations and consultative procedures that have been designed to minimize these conflicts.

Drilling Rigs

Before drilling can commence, operators are normally required, as a condition of their petroleum production and exploration licenses, to obtain consent from the Secretary of State for Energy (Petroleum Production Regulations 1976 [18] – clause 7 in Schedule 7). Consent from the Trade Minister may also be required under section 34 of the Coast Protection Act 1949 [19] as extended by section 4 of the Continental Shelf Act 1964 [3], since placing a drilling structure or vessel presents a potential obstacle or danger to navigation. Before consent is given by the Trade Minister, the hydrographer must be given at least 48 hours advance warning of rig movements. Continental Shelf Operations Notice number 16 (revised) [20] requests operators to inform the Coast Guard of the final location of all mobile drilling rigs in UK waters.

Platforms

Under section 34 of the Coast Protection Act 1949 [19] as extended by section 4 of the Continental Shelf Act 1964 [3] consent for establishing "permanent" installations is required from the Department of Trade. Such consents require notification to the hydrographer and also contain buoying and marking requirements.

Permanent installations are protected by safety zones of 500 meters established by orders made under section 2(1) of the Continental Shelf Act 1964 [3]. Ships of all nationalities are prohibited from going within the 500-meter safety zone, but special exception is made for vessels having legitimate business with the installation and for any ship that is dealing with an emergency or is itself in difficulties or distress. Such safety zones had been established around 68 installations by May 1978.

Pipelines

Consent for laying submarine pipelines must be obtained from the Secretary of State for Trade under section 34 of the Coast Protection Act 1949 [19] and from the Energy Minister under section 20 of the Petroleum and Submarine Pipe-lines Act 1975 [21]. Anyone wishing to construct a subsea pipeline is required to obtain a works authorization.

Section 21(3) of the Petroleum and Submarine Pipe-lines Act 1975 [21] enables the Secretary of State for Energy to include in the authorization under section 20 terms about "the steps to be taken by the person authorised to avoid or reduce interference by the pipeline with fishing." In addition, under the terms of schedule 4, part 1, 2b, if the Secretary of State receives an application that has to be considered further, he may give "the applicant such directions with respect to the application as the Secretary of State considers appropriate." These directions may include a requirement "to serve a copy of the notice on such persons as the Secretary of State directs" (schedule 4, part 1, 3c). Who is consulted is a matter for the Secretary of State to decide, but in the cases considered so far the main UK fishermen's federations have been included in the list of persons to whom notice has been served. The Secretary of State may also require the route of a submarine pipeline to be altered in the light of representations made to him (schedule 4, part 1, 4). Any authorizations issued under both the Coast Protection Act 1949 [19] and the Petroleum and Submarine Pipe-lines Act 1975 [21] would require that the pipeline be trenched to allow burial by natural backfill. The normal requirement would be for the pipeline to be covered to a depth of one meter. The authorization issued by the Department of Energy would also include provisions forbidding the dumping of waste material and the Department of Trade consents cover the conditions relating to buoys during pipeline operations.

Earlier legislation concerned with submarine cables has been adapted to protect pipelines from damage by anchors or fishing gear. Article VII of the convention scheduled to the Submarine Telegraph Act 1885 [22], as applied by section 8 of the Continental Shelf Act 1964 [3], provides that owners of ships or vessels who can prove that they have sacrificed an anchor, net, or other fishing gear in order to avoid injuring a submarine pipeline shall receive compensation from the owner of the pipeline. The same legislation makes it an offence to unlawfully and wilfully, or by culpable negligence, break or damage a submarine pipeline.

The Submarine Pipe-lines (Inspectors) Regulations 1977 [23] set out the powers and duties of inspectors concerned with pipeline operations. Under the regulations inspectors are empowered to require a submarine pipeline to be shut down to avoid the risk of accident or pollution.

Abandoned or Suspended Wellheads

It is a normal condition of the granting of Exploration and Production licenses that government consent is required for the abandonment or suspension of drilling or production activities on any well (Petroleum (Production) Regulations 1976 [18] – clause 7 in Schedule 7). Continental Shelf Notice number 11 [20] specifies that it is a requirement on the abandonment of a wellhead to submit a certificate to the effect that the seabed is free of all obstructions.

The consent issued by the Department of Trade for a drilling structure or vessel also specifies that, where the water depth is 45 meters or less, the height of the projection above the seabed should be not more than two meters and also requires suspended wellheads to be marked as required by the Secretary of State for Trade, if at any time he considers this necessary for the purpose of preventing obstruction or damage to navigation. The consent also requires details of all buoys marking wellheads to be notified to the hydrographer. Regular updated lists of the positions of wellheads and other fixtures are issued for the information of mariners by DAFS/UKOOA [24].

Buoys and Marking of Offshore Installations

Requirements relating to buoys and marking offshore installations are covered by the Department of Trade consents issued for pipelines, permanent installations, and drilling structures or vessels as indicated above. The Department of Trade consents also require buoys to carry identification markings indicating the buoy's position and its ownership.

Debris

The Dumping at Sea Act 1964 [25] makes it an offence for substances or articles to be dumped in UK territorial waters or outside these waters, if dumped from a British ship or marine structure, without a license from the appropriate fisheries department. The provisions of the Dumping at Sea Act were subsumed under section 45 of the Petroleum and Submarine Pipe-lines Act 1975 [21] for the laying of submarine pipelines. However, conditions in the authorizations issued under the Petroleum and Submarine Pipelines Act 1975 for pipelines, consents under the Coast Protection Act 1949 [19] for drilling structures or vessels, and the licenses issued under the Offshore Petroleum Development (Scotland) Act 1975 [26], all contain some reference to control or elimination of debris. Continental Shelf Operation Notice number 8 [20] draws attention to some of the problems created by debris and recommends that all waste materials be disposed of ashore.

Arrangements for the compensation of fishermen whose nets have been damaged by debris have been established by the oil and fishing industries. The local fishery officer assists individual fishermen in submitting their claims. Where the incident appears clearly attributable to the activities of an individual operator, the claim is submitted to him. However, if it is not, or if a claim referred to an oil company is rejected on the ground that the debris was not considered to be associated with his operations, a claim may be considered under a compensation scheme for unattributable debris funded by the UK Offshore Operators' Association (UKOOA). The fishing industry, as represented by the Scottish Fishermen's Federation and British Fishing Federation, is responsible for operating the scheme and to this end have arranged the appointment of a management committee with representatives from the two federations. The committee meets at suitable intervals to consider claims, and settlement is at the discretion of the committee, depending on the merits of each individual case. The committee's decision on each claim is final and binding. In funding this scheme, the UKOOA have imposed a condition that any settlement will not imply a legal responsibility on the part of the oil industry and will be on the understanding that the claimant waives all right to claim against a member company of the UKOOA.

General License Conditions

Exploration and production licenses are issued to operators by the Department of Energy under the Petroleum (Production) Act 1934 [4] and the Continental Shelf Act 1964 [3]. It is a term of such licenses that the licensee shall not carry out any operations in such a manner as to interfere unjustifiably with navigation or fishing, or with the conservation of living resources of the sea.

Pollution

Most of the above items relate directly to interference with fishing and navigation, but the impact of oil itself is also relevant in terms of fouling of nets and fish, and of toxic effects in the environment. The best approach to this problem is clearly the prevention of spillage. This obviously involves good management, training, and the adoption of the best operating procedures, all elements necessary for the safe operation of the platforms discussed previously.

The discharge of suitably treated oily water is, however, necessary for the operation of most offshore oil installations, particularly near the end of an oilfield's life, when large volumes of water are produced along with the oil. These are controlled by section 23 of the Prevention of Oil Pollution Act 1971 [27], as amended by section 45(2) of the Petroleum and Submarine Pipe-lines Act 1975 [21]. This requires oil operators to obtain permission (or more strictly an exemption from the provisions of the 1971 Act) for the discharge of oily water. This permission is given only with stringent conditions, taking into account the amount of oil in the final effluent, the capabilities of the treatment plant, the total volume of the discharge anticipated, and the dispersing capability of the environment. Some ten exemptions have already been issued for offshore installations. The total quantity of oil released so far in such controlled discharges on the UK continental shelf has been estimated to be less than 200 tons. This can be compared with discharges in excess of 1,000 tons per year from certain refineries, and accidental spills of more than 20,000 tons in the *Amoco Cadiz* incident.

Oil Spill Contingency Planning

Each offshore operator is responsible for cleaning up any oil spills that result from his activities. He is required to have a contingency plan covering the action he would take and the resources he would deploy in such a situation. In practice, the operators have limited cleanup resources at the platforms, but primarily rely on pooled resources held at some four centers around the UK coasts. In a given incident, an operator would be required to report a spill to the Department of Energy and the Coast Guards and deal with the pollution in accordance with his plan and the guidelines laid down by government. The government would monitor the operator's activities, offering advice and assistance where necessary. There would be full consultation with fisheries departments and the Nature Conservancy Council on the appropriate treatment strategy following any major incident.

Civil Liability for Oil-Pollution Damage

This is presently covered by the Offshore Pollution Liability Agreement (OPOL) [28] which is a voluntary scheme set up by offshore operators to cover strict liability for oil-pollution damage and remedial measures from offshore operations up to US $25 million per incident. OPOL covers escapes or discharges of oil from offshore facilities within the jursidiction of the UK, France, the Federal Republic of Germany, the Republic of Ireland, the Netherlands, and Norway. Claims are normally made directly to operators, the location of the facility being the governing factor, so that claims can be made from victims outside the countries listed above. All operators currently active on the UK continental shelf are members of OPOL.

At a conference sponsored by the UK and held in London in December 1976, the UK, together with France, the Federal Republic of Germany, Belgium, the Netherlands, Norway, Sweden, Denmark, and the Republic of Ireland, agreed on the text of an international convention under which compensation will be payable by offshore operators for oil-pollution damage caused by their activities in the waters off the coasts of countries which join the convention. This convention is the first of its kind in the world.

The maximum available for compensation will be US $35 million per incident from May 1977 (when the convention was opened for signature) rising to US $45 million by 1982. Operators will be required to insure against the bulk of their liability. Liability will be on a "strict" basis; that is, there will be no need for a person suffering damage to prove any fault by the operator to enable him to claim. Once the convention is in full operation, a victim of pollution caused by offshore oil operations will be able to bring a claim, and receive compensation, either in the courts of the country where damage is suffered or in the courts of the country that licensed the installation concerned.

To date, the UK, Norway, Sweden, and the Netherlands have signed the convention, which requires ratification by at least four countries to come into effect. Legislation that would enable the UK to ratify the convention was in preparation at the time of writing.

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22 Submarine Telegraph Act 1885 [48 and 49 Victoria Chapter 49], HMSO.
23 The Submarine Pipe-lines (Inspectors etc.) Regulations 1977 [S.I. 1977 No. 835], HMSO.
24 Oil Installations in the North Sea, issued by Department of Agriculture and Fisheries for Scotland on behalf of the United Kingdom Offshore Operators' Association.
25 Dumping at Sea Act 1974 [Chapter 20], HMSO.
26 Offshore Petroleum Development (Scotland) Act 1975 [Chapter 8], HMSO.
27 Prevention of Oil Pollution Act 1971 [Chapter 60], HMSO.
28 OPOL, Offshore Pollution Liability Agreement, The Offshore Pollution Liability Association Limited, London.

7.7 AN OPERATOR APPROACH TO BLOWOUT PREVENTION*

Introduction

This subject is very broad and, rather than go into details about preventing blowouts, only the most important points will be mentioned. This means, of course, that this section will be rather sketchy, but on the other hand it gives an opportunity to highlight the key elements and aspects of the subject.

Prevention

Figure 7.7.1 presents some of the key elements in blowout prevention. The four basic elements are: studies and programs; material, equipment, and services; personnel;

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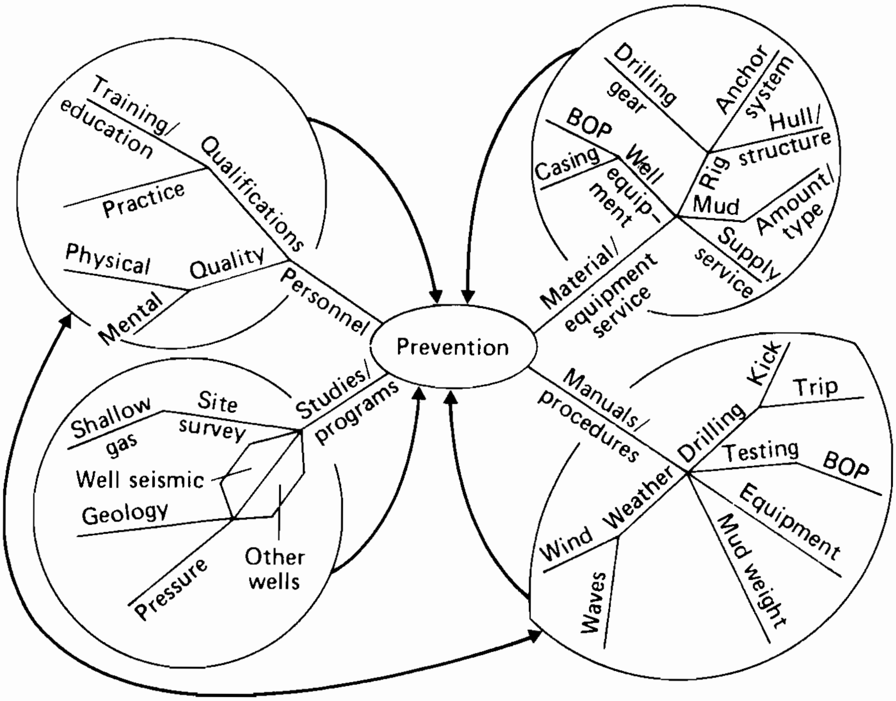

FIGURE 7.7.1 Key elements in blowout prevention.

and manuals and procedures. The figure gives examples of the various aspects, problems, and equipment included in each element. Each of the four elements comprise physical, or at least fairly concrete, tangible items. The very close connection that exists between the third and fourth elements is apparent. The figure also indicates how experience from the different elements should be fed back into a total prevention system.

Basic Approach to Safety

Having defined the key physical and tangible elements that are of importance for safety, it is now necessary to draw up a philosophical and methodological approach to blowout prevention. How should this task be approached, or at least how should an acceptably low risk level be achieved?

Figure 7.7.2 presents a reasonably systematic approach. Note that the total approach includes a feedback loop, and that the total safety requirements are the sum of the authorities' minimum requirements plus the company's own requirements. Risk control is achieved through preventive methods, such as reliability techniques, quality assurance, safety features, etc., and corrective methods, such as safety features, contingency plans, equipment,

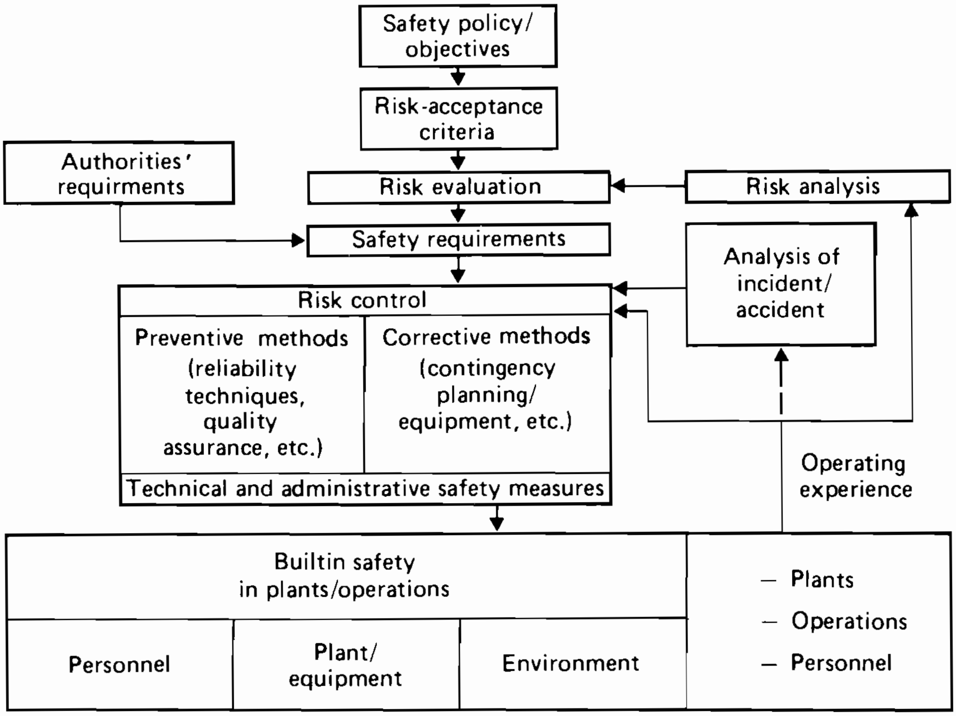

FIGURE 7.7.2 Basic overall approach to a safety strategy.

etc. The risk-control elements lead to a certain built-in level of safety in the plant itself and in its operation. Operation of the plant gives information about the plant itself, including its workings and personnel, which can be fed back into the system.

It should be noted that this kind of approach, although it seems simple on paper, requires the expenditure of a great deal of effort and resources in such activities as data collection, registration and digestion of data, risk analysis, etc. It also imposes stringent requirements on the organization concerned.

Organization

The basic approach described requires a well-designed organization with a clear definition of responsibility, working methods, etc., and also the availability of the necessary resources, people, and money.

Before discussing organizational matters related to safety in more detail, the system of organization within Statoil will be outlined as a point of reference (see Figure 7.7.3). Figure 7.7.4 shows how the organization described in Figure 7.7.3 actually works in practice in regard to safety matters.

The two latter figures illustrate some general principles and other points. (Note that the different types of arrows used in Figure 7.7.4 are intended to represent different

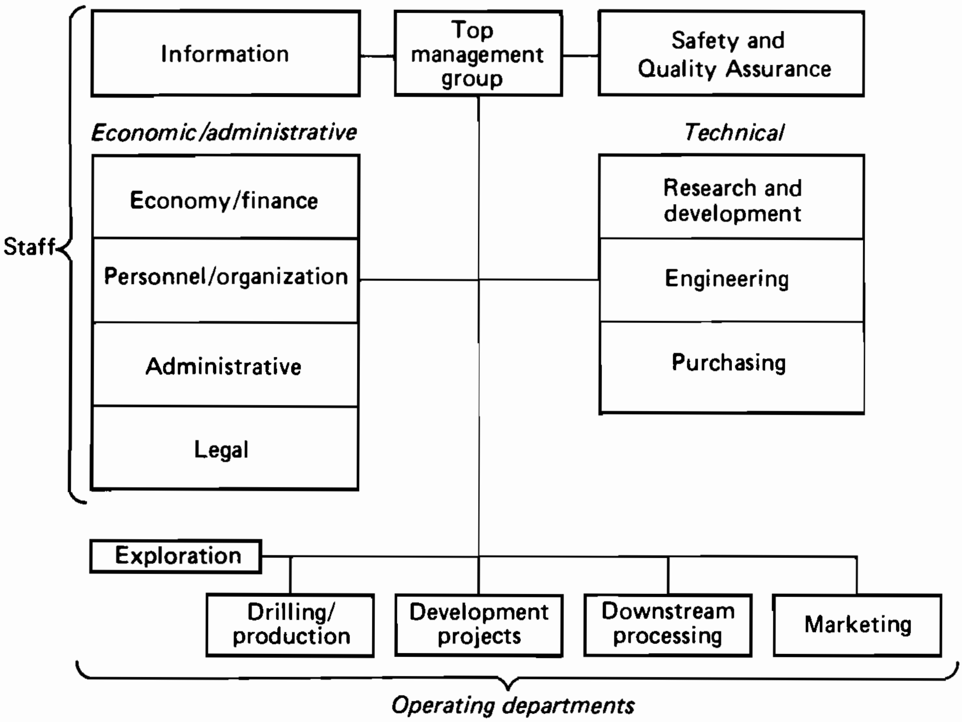

FIGURE 7.7.3 The safety organization used by Statoil.

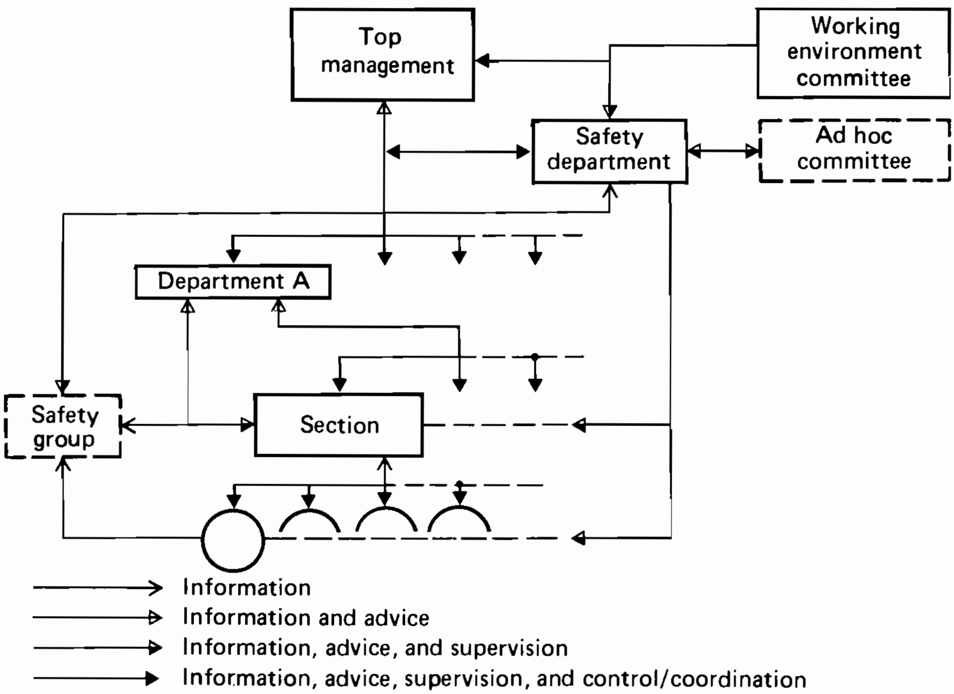

FIGURE 7.7.4 Functional operation of the safety organization in Figure 7.7.3.

"strengths.") A basic principle is that the various parts of the organization are directly responsible for the safety and quality of the projects and operations they are running, although the Safety and Quality Assurance Department has overall and supervisory responsibility for these matters. This setup implies some degree of independence, but also some duplication of responsibility for safety and quality-control measures. However, the system is designed to achieve the required amount of "self-control" or "self-policing" that is a basic feature and principle of Norwegian safety regulations.

7.8 MEASURING SOCIAL RISK AND DETERMINING ITS ACCEPTABILITY*†

Introduction

The selection of regulatory strategies for North Sea oil development raises issues common to the regulation of large-scale technologies in several different fields. The most notable of these concerns the measurement of social risk and the determination of its acceptability. This section presents a decision-analytic approach to resolving some of these issues, describes a method for developing a risk measure, and considers several approaches to defining acceptable levels of risk. Safety performance objectives are developed for use as guidance in drafting regulations. The technique is presented in terms of a specific example: regulating nuclear waste management. However, the basic features are equally applicable to the problem of regulating North Sea oil development.

The central feature of this method is the reduction of a multidimensional description of possible losses to a single risk measure. In the example, these dimensions involve different types of radiological health effects and the circumstances in which they are incurred. For North Sea oil, the dimensions could, for example, be the population losses incurred by different species of flora and fauna in different locations. In the example the single dimension of the risk measure is in units of equivalent current fatalities or lives saved, while in the North Sea oil case the dimension could be in any standardized units of environmental loss or improvement.

The role of a risk measure in developing regulations may be clarified by a brief example. Consider a hypothetical choice by the Nuclear Regulatory Commission (NRC): whether or not to require increased waste packaging over what is currently planned. A risk analysis might show that this move would decrease the risk of radioactive release to future generations, but increase the risk to current radioactive-waste workers. A radio-

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logical risk measure combines these two forms of risk, so that the net effect on overall risk can be evaluated. If in fact the increased waste packaging is found to reduce overall social risk, the risk measure could be used to determine whether or not the risk represented by the waste-management system would be acceptable with and without the increased waste packaging. If the increased waste packaging is found to be necessary to reduce the overall risk to an acceptable level, or if the reduction in risk is found to be cost-effective, the analysis would recommend the more stringent packaging regulation. In this example, the risk measure is used directly in evaluating a regulation. However, the risk measure itself can be rather complex, and not amenable to convenient guidance in drafting regulations. For this reason, simpler versions of the risk measure need to be developed and used as performance objectives.

The Basic Approach

Nature of the Risk Measure

Developing a risk measure can be characterized as a basis for performance-based regulations, where "performance" is specified to be risk to humans; but at what level should this performance be measured? Consider the sequence of uncertain consequences of a regulatory strategy depicted in Figure 7.8.1. The square node at the left of the figure represents the decision faced by the NRC: a choice among regulatory strategies. Each branch to its right represents a particular decision, a particular set of regulations. Each circular node in the figure represents a state where any number of random events can take place, each represented by a branch to its right. If this tree were drawn completely, there would be a circular node at the right end of each branch, each with its set of branches.

Each regulatory strategy results in a probability distribution over waste-management systems. Given a particular management system, there results a probability distribution over amounts of radioactivity released. Each level of release results in a probability distribution over concentrations of radionuclides in the nearest aquifer, and so on through exposure, dose, and finally, health effects.

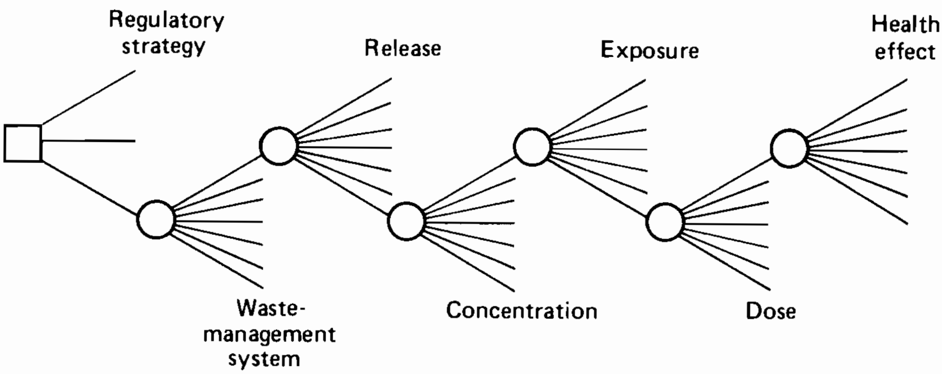

FIGURE 7.8.1 Schematic diagram of the uncertain effects of a waste-management regulatory strategy.

A regulatory strategy can be evaluated in terms of the possible releases from the resulting waste-management system, or possible resulting concentrations, exposures, doses, or health effects. As will be explained later, evaluating different types of risks involves value judgments that may not be most appropriately made by people trained in radiation physics. Because of this, the risk measure should be in terms that nontechnical people understand and care about. These considerations specify that the evaluation be at the health-effect level. This specification assumes that the public does not care about dose or exposure except for the health effects that would result. It also assumes that the people whose values are to be used understand the implications of a health effect (cancer, etc.) better than they do the implications of a dose (rem, etc.). Note that to develop a risk measure in terms of health effects does not mean that performance objectives, regulations, regulation guides, or compliance measures must be expressed in these terms. These other levels of specification must be chosen after considering their implementability. Regulations, for example, may be expressed in terms of release, even though they were developed using a health-effect risk measure, or dose-level performance objectives, as a basis.

Structure of the Evaluation Problem

Once it has been established that the risk should be expressed in terms of health effects, two basic evaluation problems remain. First, there are several different types of health effects. A cancer can be fatal or nonfatal. It can occur in a worker who in some sense has accepted the risk, or it can occur in a person who has no choice in the matter. It can occur now or in a future generation. An example given later considers a risk measure that involves twelve different types of health effects. These health-effect types must be evaluated by a single index that incorporates value tradeoffs between types, either implicitly or explicitly.

The second basic evaluation problem involves the uncertainty in exactly what health effects will result from a given regulatory strategy. As depicted in Figure 7.8.1, there are several stages between a regulatory strategy and a health effect, and each stage has a degree of uncertainty associated with it. To measure simply the expected set of health effects would miss entirely any social aversion to uncertainty. There may be a special public sensitivity to very-low-probability, very-bad-consequence scenarios [1]. To the extent that it exists, this aversion to uncertainty should be incorporated into the risk measure in a logical, self-consistent manner.

Figure 7.8.2 shows the way these evaluation problems fit into an evaluation structure. As with Figure 7.8.1, the problem is presented as that of deciding among regulatory strategies. The several random node fans of Figure 7.8.1 can be collapsed mathematically into the single probability distribution fan of Figure 7.8.2. Each (*i*th) branch of the circular (random event) node of Figure 7.8.2 represents a sequence of events with a joint probability p_i, which results in the set of health effects $\{x_{i_1} \ldots x_{i_{12}}\}$. This is the "technical probability judgment" segment of Figure 7.8.2. (The number of elements is selected to coincide with the example given later.) Finally, the n-by-twelve matrix in the middle of Figure 7.8.2 must be evaluated in terms of a single overall risk measure. This can be done by determining a health-effect scalar equivalent for each twelve-element set of health effects x_i', then determining a health-effect certainty equivalent $\hat{x}_B$, or a health effect that is equivalent in social value to the probability distribution over health-effect

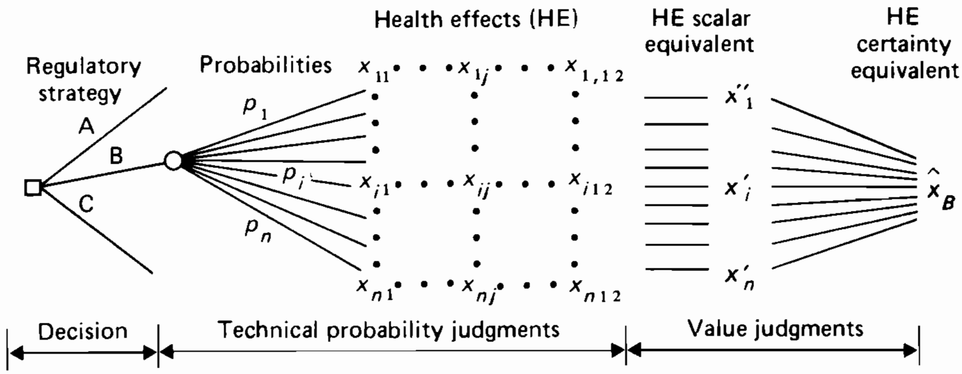

FIGURE 7.8.2 Evaluation of a regulatory strategy, accounting for multiple health-effect types and uncertainty.

scalar equivalents $\{p_i, x_i'\}$. This process is represented by the "value judgment" segment of Figure 7.8.2. Once the health effects of a given regulatory strategy have been assessed on a single risk measure $\hat{x}$, different regulatory strategies can be compared in simple cost-versus-risk terms, and acceptability of risk can be expressed in terms of an accept/reject limit on the risk measure.

Note that one advantage of the decision-analytic structure is the division of labor between technologists and value source people. The technologists are asked only for technical probability judgments, while the value source people are asked only for value judgments.

Evaluation Method

The names of the segments of Figure 7.8.2 are carefully chosen. The evaluation of the n-by-twelve matrix cannot be done without using social judgments, implicitly or explicitly. The field of decision analysis has developed methods for incorporating individual value judgments into a self-consistent evaluation model [2,3]. The method to be outlined here is multiattribute utility analysis, developed by Keeney and Raiffa [4]. The essence of the approach in this context is that a person whose values are to be modeled is asked to make choices between very simple sets of health effects and two-element probability distributions over health effects. Some choices are designed to reveal structural properties of the person's preferences (e.g., additivity under certainty, additivity under uncertainty, etc.). Other choices are designed to reveal value tradeoffs between types of health effects. Still other choices reveal the person's attitude toward uncertainty. The preference function that satisfies the structural properties of the person's preferences is then fitted to his value tradeoff and uncertainty attitude choices.

If certain behavioral assumptions are satisfied, then the person's preferences about health effects can be represented by a utility function of the form

$$U(\boldsymbol{x}_i) = \sum_j k_j u_j(x_{ij}) \tag{1}$$

or

$$U(x_i) = \prod_j [1 + Kk_ju_j(x_{ij})] \tag{2}$$

where $x_i = \{x_{i1}, \ldots, x_{i12}\}$ is a set of health effects (HE), K is a parameter reflecting the degree of complementarity among HE types, k_j is an importance weight for HE type j, and u_j is the von Neumann–Morgenstern utility function on HE type j. The u_j, k_j, and K values all represent different qualities of the person's value tradeoffs. This utility function can be used to get the HE scalar equivalent x_i' for each x_i:

$$\begin{aligned} x_i' &= x_1'' \\ x_1'' \ni U(x_i) &= U(x_1'', x_2^0, \ldots, x_j^0, \ldots, x_{12}^0) \end{aligned} \tag{3}$$

where each x_j^0 is a standard value for its HE type.

The utility function for eqn. (1) or (2) is a von Neumann–Morgenstern utility function [5]. This means that the probability distribution over sets of health effects resulting from a given regulatory strategy $\{p_i, x_i\}$ can be evaluated by the expectation over utilities of each possible outcome:

$$\bar{U}(\{p_i, x_i\}) = \sum_i p_i \cdot U(x_i) \tag{4}$$

The curvature of the utility function $U(x_i)$ represents the person's attitude towards uncertainty. An uncertainty-averse person will have a concave-downward utility function, in which case eqn. (4) discounts the value of a regulatory strategy according to the degree of uncertainty in the outcome. In the same manner as eqn. (3), an HE certainty equivalent $\hat{x}$ can be defined for each regulatory strategy, represented by the resulting $\{p_i, x_i\}$:

$$\begin{aligned} \hat{x} &= \hat{x}_1 \\ \hat{x}_1 \ni \sum_i p_i U(x_i) &= U(\hat{x}_1, x_2^0, \ldots, x_j^0, \ldots, x_{12}^0) \end{aligned} \tag{5}$$

where again the x_j^0 values are standard.

The HE certainty equivalent $\hat{x}$ derived above is the risk measure for the regulatory strategy represented by the resulting $\{p_i, x_i\}$. This risk measure can be expressed as a function of $\{p_i, x_i\}$ by inverting eqn. (5):

$$\hat{X}(\{p_i, x_i\}) = U^{-1}\left(\left[\sum_i p_i U(x_i)\right], x_2^0, \ldots, x_j^0, \ldots, x_{12}^0\right) \tag{6}$$

where $U^{-1}(\cdot)$ is the inverse of the multiattribute utility function $U(x)$, from the utility into the first argument, all other arguments held at standard values.

Equation (6) emphasizes the role of $U(x)$ as a transform equation. If the dimension selected for the risk measure is, for example, the number of current fatalities, then

$\hat{X}(\{p_i, x_i\})$ is the number of "equivalent current fatalities." That is, $\hat{X}(\{p_i, x_i\})$ is the number of current fatalities such that a situation giving rise to $\{\hat{X}(\{p_i, x_i\}), x_2^0, \ldots, x_{12}^0\}$ is held to be equivalent to the situation giving rise to the probability distribution $\{p_i, x_i\}$. Note that the intermediate step of finding the scalar equivalent x_1' for each x_i is not necessary with the multiattribute utility approach, but was included in this discussion to identify clearly the two evaluation tasks: modeling value tradeoffs and modeling attitude toward uncertainty.

The development of a risk measure has now been described. Reducing the complex description of risk $\{p_i, x_i\}$ down to a single meaningful risk measure such as equivalent current fatalities provides a basis for comparing two regulatory strategies, for comparing reductions in risk with the cost of achieving those reductions, and for comparing the risk of nuclear waste management with the risks of other technologies. The usefulness of these comparisons for providing guidance in drafting regulations will be discussed later. The central points of the present discussion are that value judgments are necessary to this process, and that the method presented here provides a way of incorporating these values in the appropriate segment of the analysis in a structured, self-consistent way.

Overview

In terms of the method described above, developing a risk measure and performance objectives can be organized into four steps: (1) develop the form of the multiattribute utility function on health effects $U(x)$ to be used to derive a risk measure; (2) fit this utility function to the values of panels of people; (3) determine an accept/reject limit on the risk measure that is derived from the fitted utility function; and (4) develop simple, implementable versions of this risk measure and accept/reject limits to use as performance objectives. The major issues to be resolved in implementing these four steps will now be discussed and an example risk measure presented.

Major Issues in the Development of a Risk Measure and Performance Objectives

Issues Concerning the Form of the Risk Measure

Scope of the Risk Measure. The risk measure developed in this example is limited to radiological risk to humans. It omits, for example, mechanical risk to miners, environmental risk, and risk to fish. This limitation in scope becomes important if minimizing radiological risk to humans results in an important increase in another form of risk. For example, radiological risk to humans could be minimized by requiring an extremely deep repository, at a significant expense in increased cave-in risk to miners. For this reason, the risk measure developed here can only be considered as one of many inputs into the regulation-drafting process.

Aggregating Values. The values to be modeled in the risk measure are elicited from more than one person. Those individual values must be aggregated into a single preference structure. This, of course, is one form of the central problem of social choice, and has been treated at great length in the literature [6, 7]. The method adopted in this development involves summing the different utilities. The interested reader is referred to the report by Brock and Sauer [8] for a detailed explanation and justification of this method of aggregation.

Aggregating Impacts: Equity. Any choice involving the regulation of nuclear waste implicitly involves an important equity choice. Such a choice affects the level of risk imposed on workers and future neighbors of the waste-management system, and the amount of economic benefit distributed to electricity users and the general economy. Any assessment of the impacts of a waste-management regulatory strategy should take into account this unequal distribution of risks and benefits. But the proper way to incorporate consideration of this inequity in drafting regulations is far from clear.

One approach to this problem is to include monetary compensation to the neighbors of the repository in the plans for a waste-management system. This approach does not lend itself to incorporation in the risk measure. In fact, the risk measure, as it has been presented here, cannot by itself be sensitive to the equity issue, since it only measures the risk side of it. However, the equity issue can be incorporated in this approach in setting the accept/reject limit on the risk measure. The more stringent the limit, the more money spent to reduce risk. As a result of this consideration, the amount of money to be spent to save an equivalent current life, that is, to reduce $\hat{X}(\{p_i, x_i\})$ by one, is a value tradeoff to be measured in the value elicitation. The magnitude of this value tradeoff reflects the desire for equity directly, since it represents the amount of money that should be given up by the people who will benefit for the sake of reducing the hazard to those at risk. The details of how this judgment can be used to set the accept/reject limit on the risk measure is explained below.

Normative versus Descriptive Nature of the Risk Measure. Several choices must be made in developing the risk measure that involve the degree to which the measure is normative as opposed to descriptive of public values. For example, suppose that the people whose values are to be assessed feel that a technology is unacceptable if one possible consequence is very bad, independent of its probability. The risk measure as developed here cannot be descriptive of such values. In fact, this sort of judgment cannot arise in the value-elicitation procedure, which carefully separates probabilities from values. Incorporating attitudes toward uncertainty in the risk measure conforms to the von Neumann–Morgenstern expected utility approach. The structure of the evaluation (see Figure 7.8.2) incorporates probabilities in a logical, self-consistent way, independent of value judgments. Combining these probabilities with values in the expected utility calculation (4) allows a very low probability to mitigate the importance of any possible consequence, while at the same time modeling disproportionate aversion to very bad consequences, and aversion to uncertainty.

Consider a second example of normative/descriptive choice: suppose the people whose values are to be assessed prefer a naturally-caused cancer to an identical, nuclear-caused one. The risk measure as developed here cannot be descriptive of these values either. This sort of judgment cannot arise in the value-elicitation procedure, which assesses values about health effects without specifying the cause. The analysis is designed to avoid biases that arise from pronuclear or antinuclear attitudes. The point of the risk measure is to evaluate the risk, independent of its cause.

On the descriptive side, the risk measure is to be fitted to individual value tradeoffs between different types of health effects, and attitudes toward uncertainty.

Fitting the Risk Measure. A key issue in the form of analysis described here is selecting the people whose values are to be incorporated in the risk measure. Ideally, the values to be represented are those of the general public. However, the value-elicitation process requires extensive face-to-face interviews with a very skilled interviewer, only one person being elicited per interview. With such expensive interviews and limited resources, a large-sample survey is not feasible. In development of a nuclear waste-management risk measure at Lawrence Livermore Laboratory [9], the sample was limited to less than sixty people. The people interviewed, while they were elicited individually, were categorized into three "panels."

The first category was the "advisor" panel, a group of people who, because of their profession or high station, were considered to be acceptable sources for expressions of public values. Their value expressions were generally respected because of the respectability of the value source. The second category was the "polarized" panel. This was a group of people who had openly and actively taken definite stands on the issue of nuclear waste management. This panel was balanced between pronuclear and antinuclear people. Their values were of interest because they had thought through the issues, were highly motivated, and to some degree reflected the political climate that the NRC must face in promulgating regulations. The third category was the "general" panel. There was no intention that this group be representative of the general public; it was too small. It was composed of people who remain openminded about the nuclear waste issue. The values of each individual were aggregated into a single risk measure for each panel, with separate measures for the pronuclear and antinuclear polarized groups. No attempt was made to aggregate values across panels.

Converting the Risk Measure and Limit into Practical Performance Objectives

While the risk measure is at the health-effect level, for ease of implementation, performance objectives (POs) may be at a level of performance measure further to the left in Figure 7.8.1, such as the dose level. The risk measure and limit can be expressed as

$$\hat{X}(\{p_i, x_i\}) \leqslant \hat{X}_0 \tag{7}$$

where $\hat{X}(\cdot)$ is as defined in eqn. (6), and, as before, $\{p_i, x_i\}$ is a probability distribution over sets of health effects. One PO corresponding to this risk measure and limit might be

$$F(\{q_k, d_k\}) \leqslant F_0 \tag{8}$$

where $\{q_k, d_k\}$ is a probability distribution over sets of doses. Elements of each dose set d_k, or $\{d_{ik}, \ldots, d_{jk}, \ldots, d_{mk}\}$, could include dose to current radiation-waste employee, dose to future maximum-diet man, dose to future average-diet man, etc. The function $F(\{q_k, d_k\})$ is the one that best predicts $\hat{X}(\{p_i^*, x_i\})$, where $\{p_i^*, x_i\}$ is the probability distribution over sets of health effects that result from $\{q_k, d_k\}$. That is

$$p_i^* = \sum_k p(x_i | d_k) \cdot q_k \tag{9}$$

The quantity F_0 in condition (8) is selected such that, if any $\{q_k, d_k\}$ satisfies condition (8), then the resulting $\{p_i^*, x_i\}$ satisfies condition (7). Note that, since $F(\{q_k, d_k\})$ is an imperfect predictor of $\hat{X}(\{p_i^*, x_i\})$, condition (8) must be conservative with respect to condition (7). That is, there can be $\{q_k, d_k\}$ distributions that fail condition (8) that result in $\{p_i^*, x_i\}$ distributions that pass condition (7).

The function $F(\{q_k, d_k^*\})$ may be extremely complicated and not very useful guidance for drafting regulations. Perhaps a simpler form, while giving up some accuracy in the representation of values, would be a more effective PO. An example of such a PO is

$$G(\{\hat{d}_j\}) \leqslant G_0 \tag{10}$$

where $\{\hat{d}_j\}$ is the set of expected doses, or perhaps certainty equivalent doses, one for each dose dimension mentioned above. The function $G(\{\hat{d}_j\})$ is the function that best predicts $\hat{X}(\{p_i^*, x_i\})$, where $\{p_i^*, x_i\})$ results from $\{\hat{d}_j\}$. The quantity G_0 is selected such that, if any $\{\hat{d}_j\}$ satisfies condition (10), then the resulting $\{p_i^*, x_i\}$ satisfies condition (7). This PO can be simplified still further by approximating $G(\{d_j\})$ with an additive function

$$\sum_j k_j \hat{d}_j \leqslant S_0 \tag{11}$$

or even by simply putting a limit on each dose dimension:

$$\hat{d}_1 \leqslant d_1^0, \ldots, \hat{d}_j \leqslant d_j^0, \ldots, \hat{d}_m \leqslant d_m^0 \tag{12}$$

The simplest PO is one achieved by approximating the constraint of condition (7) by a constraint on only one dose dimension

$$\hat{d}_1 \leqslant d_1^* \tag{13}$$

where d_i^* is selected such that, if any $\hat{d}_1$ satisfies condition (13), the resulting $\{p_i^*, x_i\}$ satisfies condition (7).

Conditions (7), (8), and (10)–(13) represent an ordering of possible POs, from the most complex and accurate representation of values to the simplest PO at the dose level. The simpler POs are more implementable and understandable, but are of necessity less representative of public values and more conservative, as explained above. The best choice of PO depends on balancing these considerations, and can only be made well if the correlations among the various measures are known.

Determining the Acceptability of Social Risk

Up to this point the main concern has been measuring social risk; but regulations cannot be written on the basis of a risk measure alone. There must be some determination of how safe is safe enough, an acceptable risk limit, or an accept/reject limit on the risk measure. Eight different ways are presented of defining acceptable risk, followed by recommendations as to which definitions are appropriate for different levels of available information.

Definitions of Acceptable Risk Based on Considering Alternatives

The four definitions of acceptable risk presented under this heading are based on the concept that the selection of an acceptable risk limit is a decision problem, a choice among regulatory strategies involving trading off economic benefits against health risks. This choice situation is represented in Figure 7.8.3. The abscissa is the level of safety resulting from the regulatory strategy, in terms of the risk measure $\hat{X}(\{p_i, x_i\})$ discussed previously. If the risk measure is expressed in equivalent current fatalities, then the abscissa is the negative of this, or equivalent lives saved, increasing to the right. The ordinate is the net economic benefit resulting from the regulatory strategy, consumer plus producer surplus, measured in dollars. This choice of axes separates the market, or internal impacts of the regulatory strategy, from the nonmarket, or external impacts. The units of net economic benefit and safety are normalized per unit of waste, or equivalent megawatt-year (electric).

The technical opportunity frontier in Figure 7.8.3 is the set of alternative efficient regulatory strategies, each represented by its economic-benefit and safety-outcome values. An efficiency strategy is one that results in the most safety possible at a given hazard-abatement cost (determining net economic benefit), or the least hazard-abatement cost for a given level of safety. Within this efficient set, increased safety can only be obtained at increased hazard-abatement cost, that is, at decreased net economic benefit, as indicated by the negative slope of the frontier in Figure 7.8.3. While the units of the axes are

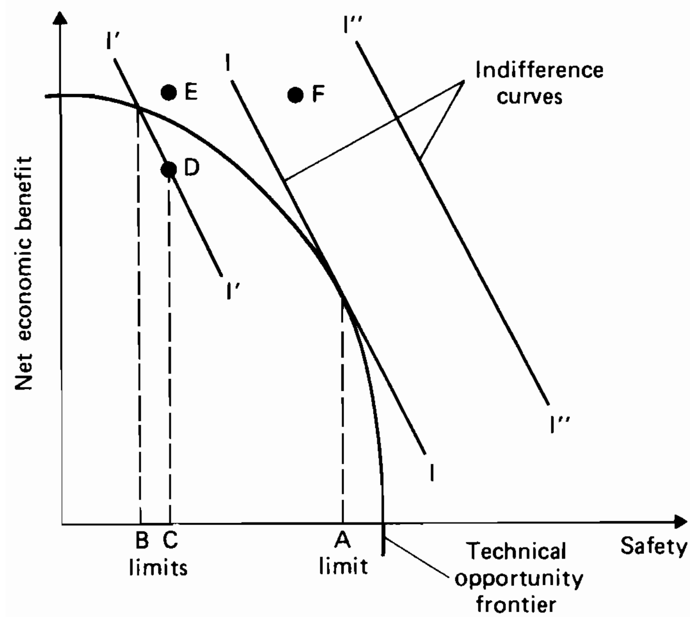

FIGURE 7.8.3 Acceptable risk limits based on considering alternatives.

normalized per unit waste, the opportunity frontier cannot be described without some assumptions about the scale of future generation of nuclear waste, in part because of the existing stock of nuclear waste.

An acceptable risk limit is a requirement that any waste-management system be at least as safe as this limit, which would appear as a left-hand constraint on the abscissa of Figure 7.8.3. But any regulation that represents social values must also be sensitive to the limit's impact on the ordinate. In the first three definitions of acceptable risk to follow, the technical opportunity frontier serves an important role by determining the economic impact of any acceptable risk limit. Assuming that any waste-management system would maximize net economic benefit subject to the acceptable risk limit as a constraint, the choice of an acceptable risk limit will lead to a regulatory strategy and industry response with an economic benefit and safety outcome described by the point on the frontier directly above the acceptable risk limit.

1. The Acceptable Risk Limit as the Limit Requiring the Waste-Management System to be Socially Optimal

With this definition of acceptable risk, the selection of the acceptable risk limit is seen as a choice among alternative ways to regulate the management of nuclear waste, or a choice among the resulting waste-management systems. In this interpretation, an acceptable risk limit is the limit on the risk measure that requires implementing a waste-management system that corresponds to the socially optimal point on the technical opportunity frontier. The criterion of social optimality as used here refers to maximizing social value, taking into account both economic and safety factors. The considerations necessary to determine the social optimum will be discussed later.

The axes of Figure 7.8.3 are not tied to any particular zero points, but mark the incremental changes in economic benefits and safety resulting from changes in regulatory strategies, here indexed by the acceptable risk limit placed on the abscissa. The ordinate values, then, do not reflect a calculation of the total economic benefits and costs of the nuclear fuel cycle, the benefit-producing system of which waste management is a vital part. Since waste-management regulations affect only the waste-hazard abatement costs, all other economic benefits and costs are considered constant. It follows that the ordinate in Figure 7.8.3 reflects only increasing hazard-abatement costs in the downward direction as regulations are stiffened. In the same manner, the abscissa in Figure 7.8.3 does not measure the total safety of the nuclear fuel cycle, but reflects only increasing equivalent lives saved as regulations are stiffened and hazard-abatement costs increased.

Determining an acceptable risk limit in this case amounts to determining the socially optimal point on the technical opportunity frontier. Determining this optimum requires trading off net economic benefit against safety, expressed in dollars per life saved. If the value of this tradeoff is set at one million dollars per life saved, then any safety measures that save lives at this expense or less are to be required. But if a safety measure would spend five million dollars to save a life, this measure would not be required. This is not a pleasant tradeoff to consider, but it is one that is made, implicitly or explicitly, every time a highway is designed or an air-travel safety regulation is set. In fact, an existing numerical guide for light-water reactors calls for US \$1,000 to be spent per man-rem reduction in release [10]. Using the value of 1.8×10^{-4} cancers per man-rem mentioned in the BEIR Report [11], with about half of the cancers fatal, this tradeoff corresponds roughly to the value of US \$11 million per expected life saved. This tradeoff may be seen as recognizing the fact that society is not willing to spend more than a certain amount of money to save an unidentified life.

In the case of waste management, the amount of money to be spent to save a life reflects more than simply the value of a life as considered in highway safety, where the populations at risk and at benefit roughly coincide. As mentioned previously, the tradeoff for waste management involves a value for equity, as it represents the amount of money to be spent by the population at benefit to reduce hazard to the population at risk. If a regulation is set that requires a greater amount of money to be spent to save a life than the amount called for by the social value tradeoff, then this regulation achieves more than a certain sort of conservatism; it also results in a misallocation of funds and a distortion of the value for equity, and so does not serve the best interests of society.

The dollars-per-life-saved tradeoff is represented in Figure 7.8.3 by the slope of indifference curves (lines) II, I′I′, and I″I″. By definition, any two points on the same indifference curve represents economic benefit and safety outcomes that are of equivalent social value. It follows that the slope of an indifference curve reflects the amount of economic benefit that can be given up to produce a particular increase in safety while maintaining the same level of social value. Clearly, indifference curves further to the right in Figure 7.8.3 link outcomes of higher social value. It follows that the socially optimal point on the technical opportunity frontier is the point where the frontier is tangent to indifference curve II. So the acceptable risk limit such that nuclear waste is managed in a socially optimal manner is represented by limit A in Figure 7.8.3; this limit leads to a waste-management system in which the amount of money spent to save an expected life matches the social-value tradeoff. A more stringent limit set to the right of limit A in Figure 7.8.3 leads to a waste-management system on a steeper part of the opportunity frontier, where more money is spent to save an expected life than is in society's best interest. A less stringent limit leads to less money spent to save an expected life than is called for by the social-value tradeoff.

Note that the analysis explained here and depicted in Figure 7.8.3 provides a clear separation of the set of efficient technical alternatives (opportunity frontier) from the critical social value (indifference curve slope, dollars per expected life saved). At the same time, the description of the set of efficient technical alternatives requires using social values, as represented by the utility function of eqns. (1) or (2), to evaluate the multidimensional health effects of each technical alternative in terms of the single risk measure of eqn. (6), the abscissa variable of Figure 7.8.3.

In sum, this definition of acceptable risk is based on an acceptable risk limit such that the resulting management of nuclear waste is socially optimal. This limit is placed on the risk measure at the point corresponding to the optimum on the technical opportunity frontier, such as limit A in Figure 7.8.3. The basic *points in favor* of this definition of acceptable risk are: the problem of what is an acceptable risk is treated in terms of the actual decision problem faced by the regulator – the choice of the socially optimal regulatory strategy; and an attempt is made to have nuclear waste managed in a socially optimal manner, with the appropriate amount of money spent per life saved. Basic *points against* this definition are: only social values within the context of nuclear waste management are optimized – risk from an optimized waste-management system would be determined as acceptable even if nonnuclear alternative technologies could provide the same benefits at lower risk; and it depends on the technical opportunity frontier, and so requires data on technical alternatives (costs, safety performance) that are hard to obtain; in addition, technical advances will expand the frontier, and so may shift the recommended acceptable risk limit.

2. *The Acceptable Risk Limit as the Limit Requiring the Nuclear Fuel Cycle to Perform Better Than the Best Alternative Fuel Cycle*

With this definition of acceptable risk, selecting the acceptable risk limit is seen as implementing a societal choice between fuel cycles (including conservation as a possible fuel cycle). By widening the scope of choice from among waste-management systems to among fuel cycles, this definition provides a criterion for acceptable risk more broadly based than the previous definition. As an example, suppose regulations for the firewood fuel cycle are being drafted. The first definition of acceptable risk grants the risk from the firewood fuel cycle as acceptable as long as it is operated at the point on its opportunity frontier where an appropriate amount of money is spent per life saved. But it could be that, in its optimum configuration, the firewood fuel cycle causes five equivalent current fatalities per megawatt-year (electric) (5 ECF/MWYe) owing to air pollution, while some alternative cycle (nuclear, coal, conservation, etc.) only causes 0.5 ECF/MWYe. This second definition then declares the risk from the firewood cycle unacceptable.

While the second definition involves a more broadly based concept of acceptable risk, it is still framed in terms of a choice. It recognizes that the problem of determining acceptable risk is not that of arriving at some absolute criterion, but rather that of picking the best of the alternatives available to society. If some absolute criterion is chosen and found to rule out all available energy alternatives, including conservation, then this criterion is meaningless. It follows that the most absolute criterion of acceptable risk must involve a comparison of fuel cycles, and must declare acceptable only the risk resulting from the fuel cycle that offers the best economic benefit and safety performance for its particular scale and application. A problem with this more absolute second definition of acceptable risk is that, in judging the acceptability of the entire nuclear fuel cycle, it provides only indirect guidance for regulations concerning waste management alone.

In order to see how to derive an acceptable risk limit from this second definition, consider the opportunity frontier of Figure 7.8.3 as the frontier for the nuclear fuel cycle. Now assume that point D represents the best alternative technology, that is, the optimum point on the opportunity frontier of all nonnuclear-energy fuel cycles. The acceptable risk limit corresponding to the second definition is limit B in Figure 7.8.3, the limit associated with the higher point of the nuclear frontier that shares an indifference curve (I′I′) with the alternative technology point. Limit B assures that the nuclear fuel cycle serves society at least as well as the alternative fuel cycle. Even if the alternative fuel cycle was represented by point E in Figure 7.8.3 – an economic benefit and safety performance not achievable by the nuclear fuel cycle – because point E is below the highest indifference curve achievable by nuclear technology (II), there exists an acceptable risk limit constraining nuclear technology to perform at least as well as point E. There is no such limit if the alternative technology is represented by point F, or any point above II. If this is the case, then no risk from nuclear technology is acceptable, and in fact an adjustment in the scale and application of the nuclear fuel cycle is in order. Note that, if the alternative technology falls below II in Figure 7.8.3, the second-definition limit is more lax than the first-definition limit (limit A).

In sum, this second definition of acceptable risk is based on an acceptable risk limit such that the resulting nuclear fuel cycle serves society at least as well as the best alternative fuel cycle. This limit is placed on the risk measure at the point corresponding to the higher intersection of the nuclear-fuel-cycle opportunity frontier and the indifference curve through the point representing the alternative technology, as in limit B in Figure 7.8.3. The basic *points in favor* of this second definition of acceptable risk are: the problem of what is an acceptable risk is treated with a very broad scope – the choice of the socially optimal fuel cycle; and an attempt is made to have the nuclear fuel cycle perform at least as well as the best alternative fuel cycle. Basic *points against* this definition are: in constraining the full fuel cycle, it provides only indirect guidance for writing regulations for nuclear waste management; it does not optimize within the nuclear fuel cycle, which may result in less money being spent per expected life saved than is socially optimal; and it depends on the technical opportunity frontiers of nuclear and nonnuclear full fuel cycles, and so requires data about alternative technologies (cost, safety performance) that are hard to obtain; in addition, technical advances will expand many frontiers, and so may shift the recommended acceptable risk limit.

3. The Acceptable Risk Limit as the Limit Requiring the Waste-Management System to be Socially Optimal and the Nuclear Fuel Cycle to Perform better than the best Alternative Fuel Cycle

This definition of acceptable risk combines the previous two. The first definition seeks to have the appropriate level of safety achieved for the waste-management technology, but may miss the fact that there is a better nonnuclear fuel cycle. The second definition assures that the nuclear fuel cycle is the best technology, but may lead to an underinvestment in safety. It seems natural to combine these two definitions, and use whichever achieves the most stringent risk limit. This idea of a double limit is essentially what is called for in the existing numerical guides for light-water reactors, which call for both absolute limits on dose and the dollars-per-life-saved tradeoff mentioned previously (see ref. 10). As explained above, using the more stringent limit means that, if the nuclear fuel cycle is the best technology for the scale and application under consideration, then the first-definition limit (limit A in Figure 7.8.3) is binding. If the nuclear fuel cycle cannot perform as well as the alternative technology for the scale and application under consideration, then the second-definition limit is binding, and no degree of safety will make the risk of the nuclear fuel cycle acceptable.

If the organization served by this analysis can only control the licensing of waste-management systems, then the scale of nuclear-waste generation will have to be taken as given. In this case, the second definition of acceptable risk does not apply when its limit would be binding, and so this third definition becomes identical to the first.

The basic *points in favor* of this third definition of acceptable risk are: the problem of what is an acceptable risk is treated in terms of a choice between socially optimized fuel cycles; and an attempt is made to have nuclear waste generated only when it is socially optimal to do so, and then to have it managed in a socially optimal manner, with the appropriate amount of money spent per life saved. Basic *points against* are identical to those detailed for definition 2.

4. The Acceptable Risk Limit as the Limit Requiring the Nuclear Fuel Cycle to be Safer than the best Alternative Fuel Cycle

Another way to define acceptable risk that retains the concept of choice among fuel cycles is to limit the nuclear fuel cycle to be safer than the best alternative fuel cycle in terms of equivalent current fatalities per megawatt-year (electric). If the best alternative is represented by point D in Figure 7.8.3, then limit C is the corresponding acceptable risk limit. This acceptable risk definition is similar to the second definition, without giving credit to a fuel cycle for greater economic benefit. Note that this definition results in an acceptable risk limit that the nuclear fuel cycle can meet even if the best alternative technology is clearly superior, as would be the case if the alternative were represented by point F in Figure 7.8.3. It may seem that this definition eliminates the need to determine a particular amount of money to be spent per life saved. However, it is the same as definition 2 with a tradeoff value of an infinite amount of money per life saved. As the two examples (alternative fuel cycles at points D and F) have shown, this extreme tradeoff can work to ease or stiffen the acceptable risk limit the nuclear fuel cycle must meet.

The basic *points in favor* of this fourth definition of acceptable risk are: the problem of what is an acceptable risk is treated in terms of the choice of the safest fuel cycle; it is an easily understood concept of acceptable risk as risk per megawatt-year (electric) no greater than the corresponding risk of the best alternative technology; and an attempt is made to have the nuclear fuel cycle operate at least as safely as the best alternative technology. Basic *points against* are: in constraining the full fuel cycle, it provides only indirect guidance for writing regulations for nuclear waste management; it does not optimize within the nuclear fuel cycle and may result in more or less money being spent per life saved than is socially optimal; and while determining this limit does not depend on the nuclear fuel-cycle opportunity frontier, it does depend on the nonnuclear fuel-cycle frontiers, and so requires data about nonnuclear alternatives (cost, safety performance) that are hard to obtain; in addition, technical advances will expand many frontiers, and so may shift the recommended acceptable risk limit to the right.

Definitions of Acceptable Risk Independent of Alternatives

The four definitions of acceptable risk presented under this heading are not based on the choice and decision concepts used above, but rather on the concepts of risk context and direct judgment. The first three of these definitions are based on the idea that a risk is acceptable if it is not too different from the context of risks experienced in everyday life, or the risks deemed acceptable by other regulations. The last definition is based simply on the idea that a risk is acceptable if it is deemed so by direct judgment. These four definitions were identified and assembled by Stephen Watson, then of Decisions and Designs, Inc., as part of the waste-management radiological performance objectives project at Lawrence Livermore Laboratory. The interested reader is referred to his discussion and comparison of these and some of the previous definitions of acceptable risk [12]; it covers points largely complementary to those raised in this section. There are several points for and against the following four definitions which will be deferred to the end, since they apply equally to all four definitions.

5. Acceptable Risk as Risk Accepted in Observed Behavior

People take risks in their everyday lives. They watch color TV, move to Denver (both activities increase radiation doses), drive cars, and use electric appliances. These risks are apparently generally accepted. It might follow that an acceptable risk limit for nuclear waste management should be set such that no individual be subject to an increase in risk greater than that caused by any of these activities. The basic *points in favor* of this definition are: it is an easily understandable concept of acceptable risk as risk no greater than risks commonly taken; and to the extent that people's behavior is a more accurate indicator of values than any stated preference, this procedure more closely represents personal values than a procedure involving a utility function fitted to stated preferences. Basic *points against* are: it does not account for the benefits of a technology as a reason for accepting the risk of that technology; and it makes several tenuous assumptions about how people behave – that observed accepted risks are taken with full knowledge of the probabilities and consequences, that people behave rationally when making risky decisions, and that people want government risk decisions to be made with the same attitude toward risk as they exhibit in everyday decisions that may not be carefully analyzed.

6. *Acceptable Risk as Risk Allowed by Other Nuclear Regulations*

The question of what risk is acceptable has in a sense already been answered for nuclear technology in the form of regulations concerning radiation safety [13]. It may follow that an acceptable risk limit should be set such that any risk due to nuclear waste management is less than the risk allowed by existing radiation safety regulations. The basic *points in favor* of this definition are: it is an easily understandable concept of acceptable risk as risk no greater than risks already sanctioned; and it has the advantage of legal precedent – it can be argued that the amount of risk has already been ruled acceptable. The basic *point against* is: it does not account for the fact that benefits result only from the full fuel cycle, of which reactors and waste management are both parts, although the risks of the two segments add up as part of the total fuel-cycle risk. The allocation of risk among different segments of the fuel cycle should be done on the basis of equal funds spent per life saved, not on an equal-risk basis.

7. *Acceptable Risk as the Risk of a Small Fraction of Natural Background Radiation*

This definition is related to definition 5 in that natural background radiation represents a context of risk against which to compare the risk of nuclear waste. In addition, there are geographical and building-related fluctuations in natural background that people do not seem to worry about. It seems reasonable, then, to define acceptable risk as some small fraction of the risk of natural background radiation, less than the risk of incremental changes in background radiation that people seem to ignore. The basic *point in favor* of this definition is: it is an easily understandable concept of acceptable risk as risk no greater than that incremental risk that is typically ignored when it occurs as a change in natural background radiation. Basic *points against* are: it does not account for the benefits involved in changing geographic location versus the benefits of nuclear power; and it does not provide a rationale for determining just how small a fraction of natural background radiation should be used.

8. *Acceptable Risk as Defined by Direct Judgment*

The most straightforward way to determine what risk is acceptable is simply to ask people. This has actually been done and reported by Fischoff et al. [1]. In this study, people were asked for their perceived benefits and risks of several different technologies and activities, and the amount of adjustment required (if any) to make the risk acceptable.

The basic *points in favor* of this definition are: it is the most easily understood process of determining acceptable risk; it accounts for the level of benefit in determining acceptable risk; and it involves the most direct expression of personal beliefs. Basic *points against* are: the rationales used to arrive at the acceptable risk judgments remain in the heads of the respondents, and so are thoroughly concealed; it requires the respondents to make judgments consistent with their actual preferences concerning a very complex matter, involving consideration of the consequences of alternative judgments of acceptability; and even if the respondents could make these judgments consistent with their actual preferences, this method assumes that they know the relevant technical opportunity frontiers. Because the respondents may not know these frontiers, their judgments may result in defining an infeasible level of acceptability. For example, the direct judgments may define an acceptable technology as one represented by a point lying above the I″I″ indifference curve of Figure 7.8.3. Yet that standard is not achievable by any technology, nuclear or nonnuclear.

Comparisons and Recommendations of Definitions of Acceptable Risk

Alternative-Independent versus Alternative-Based Definitions. The alternative-independent definitions of acceptable risk (definitions 5–8) are at first glance more attractive than the alternative-based ones (1–4) because they are easier to understand, require less difficult levels of information in their derivation, and are more absolute. However, they have a very basic flaw. While some of the alternative-independent definitions are based on comparisons of risk, none are based on the one relevant comparison: which of the alternative energy strategies serves society best?

The actual situation facing society as it makes energy-related safety decisions is a choice among energy strategies. If a definition of acceptable risk is based on anything other than this choice, it may either rule out all possible alternatives, or allow more than one, but it is very unlikely to single out the best alternative. It could be maintained that the idea of an acceptable risk criterion is to provide an absolute risk maximum, with optimization left as a second step (as in the structure of alternative-based definition 3). But if so, this absolute maximum had better allow at least one of the alternatives, or else it will be meaningless. It follows that whoever sets the maximum must refer to the set of alternatives to assure its applicability, and so finds himself determining an alternative-based maximum after all. Once the criterion is found to be alternative-based, it has lost its absoluteness and so is hard to defend unless it corresponds to one of the alternative-based definitions of acceptable risk.

One criticism often brought against the alternative-independent definitions 5–7 is that they do not allow the benefits of a particular technology to be used to justify particular levels of risk. After all, if no benefit is associated with a technology, the appropriate level of acceptable risk for this technology should be zero. This argument is a narrower version of the choice-among-alternatives approach used here. The benefits and risks of a technology are only realized to the extent that they exceed the benefits and risks of the best alternative technology.

Recommended Definitions. If analysis resources are not severely constrained, the most defendable acceptable risk criterion is the alternative-based definition 3, which combines definitions 1 and 2 into a criterion that requires safety optimization within an appropriately scaled fuel cycle. If the regulating body does not have control over the scale of the fuel cycle to be regulated, definition 3 becomes definition 1, a criterion requiring a socially optimized safety level for the regulated technology. Definition 4 is attractive in its simplicity, but could lead to an indefensible misallocation of funds.

If analysis resources are severely constrained, then the extensive information base necessary for the alternative-based definitions makes them inapplicable. In this case definition 6, acceptable risk determined by reference to similar existing regulations, becomes attractive. While it does not itself address the choice among alternatives that should be considered, it alone of the "low budget" definitions takes advantage of risk-analysis work done by others facing a similar type of risk.

An Example of a Risk Measure

As was explained above, the purpose of the risk measure is to evaluate the very complex health-effect consequences of a waste-management regulatory strategy, expressed as a probability distribution over sets of health effects $\{p_i, x_i\}$, in terms of a single number $\hat{X}(\{p_i, x_i\})$, such as equivalent current fatalities. This scalar risk measure is necessary to rank regulatory strategies in terms of the levels of safety they represent, to define the efficient set of regulatory strategies in terms of economic benefit and safety, to define the value tradeoff between economic benefit and safety in simple and meaningful terms, and to express the concept of acceptable risk in terms of a limit on the scale of the risk measure.

As shown earlier in eqn. (6), the risk measure is based on a von Neumann–Morgenstern multiattribute utility function $U(x)$. An example of this utility function will now be given. Some of the ideas are taken directly from a report by Keeney [14]; the reader is referred to it for a more complete development of some of the concepts touched on briefly here.

Arguments of the Utility Function. The arguments of the utility function can best be defined by enumerating the considerations that may affect values concerning health effects. The first of these is when the health effects occur. The time dimension can be divided into before and after the waste repository is sealed (pre-seal, post-seal). Perhaps the post-seal period can be further divided into centuries, but for clarity and brevity in this example, only two periods are used. The second consideration is how the health effects are grouped, whether or not they are bunched into catastrophes. A catastrophe is defined here as a set of health effects that are announced as having the same immediate cause. The third consideration, suggested by Keeney [14], is how the impacts of the health effects are felt. A fatality in a catastrophe has a social impact on those who read about it in the papers and a personal impact on the victim and on the victim's family. The fourth consideration is how the health effect is incurred: voluntarily or involuntarily. Perhaps a better partition here is occupational vs. nonoccupational. The final consideration included here is what sort of health effect is involved. While there can be a large number of health-effect categories, for this example only two will be considered: fatal cancers and nonfatal cancers.

Figure 7.8.4 illustrates how these five considerations can be organized into a hierarchy that exploits dependencies among categories. Note that there are no social-impact branches for nonbunched health effects, and no voluntary or occupational health effects for the post-seal period. For the two time periods used in this example, the hierarchy terminates in twelve arguments, $\{x_1, \ldots, x_{12}\}$, where each argument is simply the number of health effects fitting the description of its node in the hierarchy. Note that several health effects are counted twice, once for their personal impacts and once for their social impacts. While this requires some care in the value-elicitation process, it causes no obvious formal difficulties.

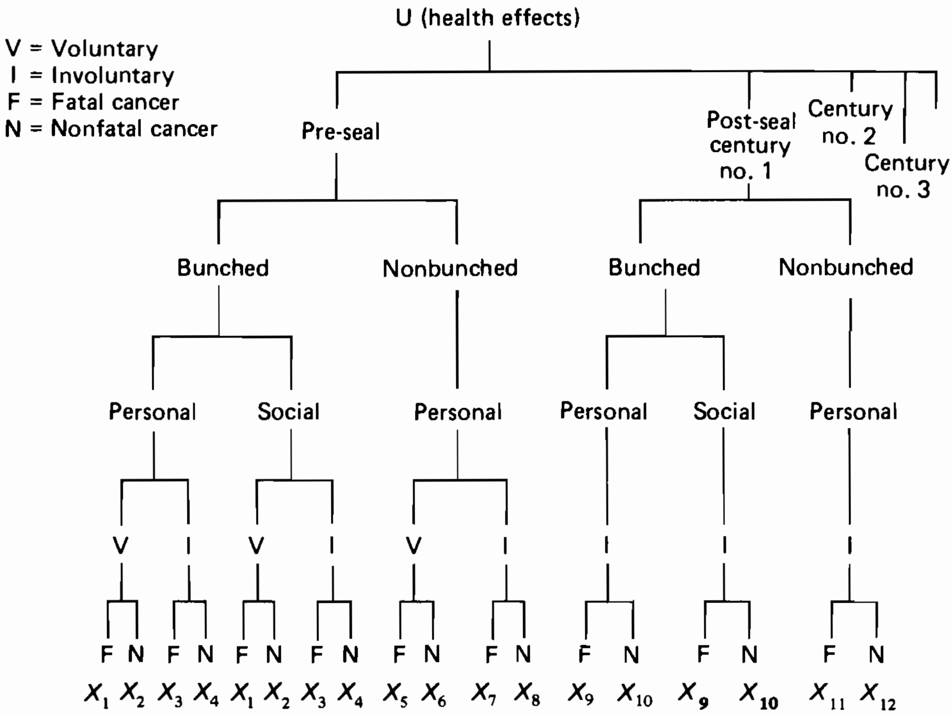

FIGURE 7.8.4 Hierarchy of value dimensions.

Structure of the Utility Function. Starting at the top of Figure 7.8.4, the first partition the utility function must aggregate over is time. Because pre-seal preferences cannot depend on post-seal outcomes, and probably a very small fraction of people impacted in the post-seal period will be alive in the pre-seal period, it seems reasonable to assume the preference structure is additive over time. Using t1 for the pre-seal and t2 for the post-seal subscript:

$$U(x_1, \ldots, x_{12}) = k_{t1} u_{t1}(x_1, \ldots, x_8) + k_{t2} u_{t2}(x_9, \ldots, x_{12}) \tag{14}$$

Because any bunched health effects will be different and considered apart from nonbunched health effects, it may be reasonable to assume additive preferences over this partition also. Using b for the bunched-effect and n for nonbunched-effect subscript:

$$u_{t1}(x_1, \ldots, x_8) = k_b u_{b1}(x_1, \ldots, x_4) + k_n u_{n1}(x_5, \ldots, x_8)$$
$$u_{t2}(x_9, \ldots, x_{12}) = k_b u_{b2}(x_9, x_{10}) + k_n u_{n2}(x_{11}, x_{12}) \tag{15}$$

The personal–social partition divides not health effects but the impacts of these health effects on two basically different populations. So here too additivity seems reasonable. Using p for the personal-impact and s for the social-impact subscript:

$$u_{b1}(x_1, \ldots, x_4) = k_p u_{p1}(x_1, \ldots, x_4) + k_s u_{s1}(x_1, \ldots, x_4)$$
$$u_{b2}(x_9, x_{10}) = k_p u_{p2}(x_9, x_{10}) + k_s u_{s2}(x_9, x_{10})$$
$$u_{n1}(x_5, \ldots, x_8) = k_p u_{p1}(x_5, \ldots, x_8) \tag{16}$$
$$u_{n2}(x_{11}, x_{12}) = k_p u_{p2}(x_{11}, x_{12})$$

The voluntary–involuntary partition is more involved. Since this partition represents mutually exclusive populations, the personal impacts can be assumed to be additive. However, it is quite plausible that the social impact will include some interaction. Using v for the voluntary-effect and in for the involuntary-effect subscript, π for the personal-impact basic health-effect utility function, σ for the social-impact basic function, and int for the interaction weight:

$$u_{p1}(x_1, \ldots, x_4) = k_v u_\pi(x_1, x_2) + k_{in} u_\pi(x_3, x_4)$$
$$u_{p2}(x_9, x_{10}) = k_{in} u_\pi(x_9, x_{10})$$
$$u_{s1}(x_1, \ldots, x_4) = k_{s,v} u_\sigma(x_1, x_2) + k_{s,in} u_\sigma(x_3, x_4) \tag{17}$$
$$+ k_{s,int} u_\sigma(x_1, x_2) u_\sigma(x_3, x_4)$$
$$u_{s2}(x_9, x_{10}) = k_{s,in} u_\sigma(x_9, x_{10})$$

Finally, since fatal and nonfatal cancers impact mutually exclusive populations, it seems reasonable that personal impacts will be additive across health-effect types. In addition, by the very nature of the personal impacts, it seems reasonable to assume additivity across impactees within each health-effect type, indicating a linear utility function. On the other hand, there may be interactions in the social impact both across and within health-effect types. Using 1 for the fatal- and 2 for the nonfatal-cancer subscript:

$$u_\pi(x_1, x_2) = k_1 x_1 + k_2 x_2$$
$$u_\sigma(x_1, x_2) = k_{\sigma,1} u_1(x_1) + k_{\sigma,2} u_2(x_2) + k_{\sigma,int} u_1(x_1) u_2(x_2) \tag{18}$$

The overall utility function $U(x)$ can be composed from equations of the forms of (14)–(18).

The elicitation procedure must assess the von Neumann–Morgenstern utility functions over the social impacts of numbers of health effects of each type (u_1, u_2). The procedure must also assess importance and interaction weights ($k_{\sigma,1}$, $k_{\sigma,2}$, $k_{\sigma,\mathrm{int}}$, etc.) corresponding to value tradeoffs between health-effect types, voluntary versus involuntary effects, personal versus social impacts, bunched versus nonbunched effects, and effects occurring in different periods.

Conclusions, Future Directions

This paper has described a method of measuring the radiological risk due to nuclear waste management that can take a complex description of the consequences of a waste-management regulatory strategy – a probability distribution over multidimensional outcomes – and reduce it to a single number, a risk measure. This risk measure is necessary to rank regulatory strategies and the resulting waste-management systems in terms of the level of safety each represents. It provides a means of identifying the set of regulatory strategies that are efficient in the sense of the most safety for a given cost. The risk measure can express the reduction in risk due to a regulation in simple, meaningful terms, so that the risk reduction can be compared with the cost of achieving it. The risk measure provides a scale on which a limit of acceptable risk can be set, and on which the risk of nuclear waste management can be compared with other risks. Several definitions of acceptable risk have been discussed, and particular definitions recommended for different levels of analysis. In addition, ways of using a risk measure and acceptable risk limit to develop performance objectives for use as guidance in writing regulations have been outlined.

Several key areas of difficulty stand out as directions for future work. One is to develop improved ways to assess public preferences, and to aggregate these performances into a single risk measure. Another is to determine a definition of acceptable risk that fits into a clear analytic framework and is agreed upon by the various parties in the political and regulatory process charged with managing hazardous technologies. The method outlined here handles only the radiological risk of a new technology. This risk analysis should be interfaced with a more comprehensive evaluation of this technology.

The method described provides a framework for the analysis of risk due to waste management, or, for that matter, any other technology. This framework can be used to organize available data into a structured basis for writing regulations to manage the risk. The method separates clearly the roles of technical probability judgments from value judgments. It also distinguishes the identification of the set of efficient technical alternatives from the crucial value tradeoff between cost and safety. This structuring of the analysis can serve to identify reasons for disagreement in questions of the safety of a particular technology, including the basic question of how safe is safe enough.

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8 WELL CONTROL

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8.1 THE DANISH RESPONSE TO WELL CONTROL*

The first oil to be discovered under the North Sea was found in the Danish sector; at the time of the Workshop, four oil and two gas fields were under development. The basic principles governing the regulation and supervision of offshore activities are somewhat different from those in force in the neighboring Norwegian sector. A single concessionaire, the A.P. Möller Company, holds a 50-year lease on all oil and gas development in the Danish sector and subleases to a group of oil companies who operate in the area. The terms of A.P. Möller's lease are very broad and they effectively limit direct governmental involvement to a fairly nominal level, except in cases where pollution has taken place. The operating company has sole responsibility for well control.

The Maersk Explorer Blowout

The blowout in the Vagn-1 exploratory well being drilled from the Maersk Explorer rig occurred on October 14, 1977. A pressure "kick" from a shallow gas pocket precipitated a series of operating errors which led to the blowout. Some attempts were made to close off the well but it seems that these were not continued for long enough. Equipment needed to stop the blowout was not immediately available but it also appears that the reasons given for abandoning the rig so early in the incident were not valid. The underlying reasons for the blowout seem to have been human error in responding to the initial well kick, compounded with subsequent errors of judgment by personnel under stress.

Additional hazards were present throughout the attempts to control the blowout. These possible dangers included the risks of explosion, underground blowout, "cratering," and the collapse of the Maersk Explorer rig under the accumulated weight of sand blown out of the well along with the gas. Fortunately, however, none of these complicating events actually took place.

*Based on comments made during the Workshop by Peter Steen, Chief Petroleum Engineer, Danish Energy Agency. Since Mr. Steen did not submit a formal paper, we present here an outline of his remarks.

Government response during the incident was coordinated by a Steering Committee composed of the Ministry of Trade as leader, the Danish Energy Agency, the Danish Geological Survey, and the Environmental Protection Agency. However, as noted above, the role of the Steering Committee was somewhat constrained by the wide-ranging terms of A.P. Möller's lease.

8.2 NORWEGIAN REGULATORY RESPONSES TO WELL CONTROL*

The Action Group and its Future Use

The Action Group set up by the Norwegian government at the time of the Bravo blowout has an impressive formal structure and it certainly operated very successfully during the Bravo incident. However, there is still room for discussion of how best to ensure its efficient operation in future. For a number of reasons the staff of the Petroleum Directorate should be responsible to the Directorate's representative on the Action Group but should normally not be subject to the Action Group's direct control. The reasons include the wide variety of emergency and ongoing tasks which the Directorate must perform, such as estimating flow rates, checking the durability of structures, organizing liaison with all the companies involved, working in the field, and handling other emergencies and near-emergencies. A blowout lasting a very long time may necessitate a change in organizational structure, such as attaching personnel from private companies to the Petroleum Directorate, for example, to advise on the location and timing of relief-well drilling.

One major issue which should be recognized is that there can be great political pressure on the Action Group to take over well- and pollution-control operations directly. To prevent this happening with undue frequency, the day-to-day regulator should be made an integral part of the Action Group, thus making it unnecessary for the Group to directly decide on too many questions for which the regulator or operator would normally be responsible. The importance of this point should be stressed: if the Action Group does move during an emergency into an organizational area already occupied by the normal regulator or operator, it can jeopardize or even destroy the close working relationships which are so necessary in more normal situations.

Well-Control Issues

Turning to more technical matters, some consideration could be given to drilling a relief well directly from the fixed production platform, rather than from a separate jack-up rig. Contingency plans in the past did not specify the availability of equipment such as emergency vessels, working barges, BOPs, valves, etc., but now more thought is being given to preparation for accidents. However, if too much equipment preparation occurs, then

*Based on comments made during the Workshop by Dag Meier-Hansen, Director, Inspection and Control, Norwegian Petroleum Directorate. Since Mr. Meier-Hansen did not submit a formal paper, we present here an outline of his remarks.

the preplanned "solution" may not fit the actual situation as it develops; therefore a planning framework is more important than a detailed plan.

Well capping and control could be made easier if these future potential problems were considered during the design stage. While the regulator should not insist on a particular solution, thereby allowing the companies to suggest a range of plans, one possibility is the installation of a fixed valve under the "christmas tree" that is present at all times so that the well is never open during a maintenance workover. Alternative operating procedures could be devised and evaluated so that each company has available a variety of procedures, for example for shutting down a well. It is important to design components and equipment so that, if accidents do occur, they proceed in such a way as to minimize their consequences. It is also important to know the threshold of damage for each given structure, so that a decision maker can minimize other damage, for example by deciding to re-ignite the flow from a blowing well to reduce the extent of oil pollution.

8.3 UK REGULATORY RESPONSES TO WELL AND POLLUTION CONTROL*

UK Organization for Well and Pollution Control

In the event of a blowout occurring in the UK sector, central government plans specify that a blowout emergency team would be set up in the operator's home port by the head of the Petroleum Engineering Division, Department of Energy (who would advise on well control). The team would also include representatives of the Department of Trade (to advise on pollution cleanup), the Ministry of Defence, and the Scottish Office (if the incident occurred north of latitude 55° N). The responsibilities of this emergency team are defined to include maintaining hour-by-hour contact with the operator, monitoring operator actions promptly, and relaying government advice. The team would report directly to a special Cabinet-Office committee at ministerial level; the actual members of the committee are never named and the precise organization would depend on the magnitude of the incident.

The Department of Trade is advised on pollution control by environmental experts in government departments (e.g., fisheries) and on nature-conservation issues (such as damage to seabird populations) by the Nature Conservancy Council.

Emergency Vessels

Since the Bravo blowout, the UK government has been studying the types of fire-fighting vessels available and their various response times. Some differences of opinion between industry and government regarding the response times and capabilities of the vessels have emerged. Further study is necessary on the relative benefits of on-platform

*Based on comments made during the Workshop by A.D. Read, Department of Energy, United Kingdom. In addition to the formal paper submitted by Mr. Read (see Section 9.1), it was felt that a summary of his remarks would be of interest.

drenching systems and fire-fighting vessels arriving at various times after the incident has started.

The real capabilities of working vessels anchored alongside a blowing platform are also under study because of the probability that they will not be able to operate at full specified capacity in very rough seas. There is a need for larger fire-fighting vessels and also for working platform vessels equipped with dynamic positioning aids so that they can maintain their positions in heavy seas. Up till now, strategies for drilling relief wells have relied on the availability in the area of numerous mobile exploration rigs; however, as the exploration drilling phase draws to a close, it may be necessary for one or two of these rigs to be purchased and kept available for emergency relief drilling. Finally, the UK government is supporting research on a single-vessel oil pick-up system for use in selected areas.

Pollution-Control Issues

Oil tankers are considered to pose a greater and more long-standing threat to the UK than oil blowouts because of the density of tanker traffic and prevailing currents in the area. Because of this mobile threat from both British and foreign tankers, the UK has had to organize its own independent clean-up system, whereas the responsibility for dealing with any pollution caused by UK-based offshore operations rests with the operators themselves. There are oil-spill contingency plans for the operators and these are discussed in more detail in Section 9.1.

At strategic points around the UK coast, stocks of government-approved chemical dispersants, information on environmentally sensitive areas, and lists of contacts for more information are maintained. The approved dispersants are used as the basic response to oil spills; toxicity regulations specify that the mixture of oil and dispersants must be no more toxic than the oil itself. Dispersal techniques are used because they are considered at present to be the only available methods which actually work in the sea conditions experienced around the coasts of the UK. If an accident occurs, operators do not automatically start spraying dispersant; spraying only takes place initially to ensure safety in the vicinity of the platform and to counter any immediate perceived threat to seabird populations. At the same time, the operator seeks immediate advice from the government on the advisability of any further spraying. In the future the UK hopes to move to a mixed response involving both mechanical and chemical methods, because it accepts that recovery (where this is possible) is environmentally preferable to dispersion.

Discussion

It is recognized that spraying dispersant on oil spilled from a platform in the UK sector can speed the arrival of oil in the Norwegian sector. There are still differences of opinion on when to spray, how long to continue spraying, and what dispersant concentration should be used. There is clearly a need to balance the risk to seabirds of oil floating on the surface and the risk to fish from dispersed oil in the water column below. Finally, it should be noted that the oil blown from the well is often at a high temperature ($\sim 100^\circ$ C); evaporation of this boiling oil and rapid degradation of oil in seawater are in fact the main routes by which the concentrations of the lighter fractions are reduced, regardless of the clean-up method used.

8.4 AN OPERATOR APPROACH TO CONTROL*

This subject is very broad in scope and therefore only an outline of the more important elements is presented here. The large number of factors connected with emergency preparedness can be appreciated by examining Figure 8.4.1. Clearly the factors may be divided into three main elements, namely personnel, equipment, and contingency plans; the figure gives some indication of the possible subdivisions of each element and also shows the close interrelation between the elements.

Contingency Plans

In Norway, Statoil has developed a system of contingency plans that can be utilized for a broad range of accidents, plants, and equipment. The system is based on the use of one overall and fairly general plan for Statoil, taken in conjunction with individual rig or plant-related plans. In the event of an accident, these two types of plans are intended to complement each other. Personnel are on call partly under the provisions of the overall Statoil plan and partly on an individual-rig (or plant) basis. Figure 8.4.2 presents the main organizational elements in the Statoil plan, plus the connections to emergency services controlled by the central authorities. The action group within Statoil can draw upon all the resources of the company as the need arises.

Cooperative Planning: the "Sector Clubs"

To increase efficiency and pool resources, thus easing the burden of emergency preparations for each field, the North Sea Operators' Committee–Norway (NSOC–N) and the United Kingdom Offshore Operators' Association (UKOOA) have collaborated in drawing up a "Code of Practice and Plan" for offshore emergencies. The Code is based on the concept of "Sector Clubs" which are groups of geographically neighboring fields cooperating in the provision of emergency equipment and services. There are a total of five such clubs in the North Sea: the four which involve both Norwegian and UK fields are shown in Figure 8.4.3, while the fifth (not shown here) lies entirely within the UK sector.

The Code defines three different steps in dealing with emergencies. Step I (up to one hour after the emergency starts) is that of immediate preparedness – evacuation and medical care for personnel and immediate fire fighting. Step II (from one hour to several days after the emergency starts) is the phase of stabilization – including long-term fire fighting. Step III (from several days onwards) is the stage of final control and correction – including well control, capping, relief-well drilling, any additional fire fighting, etc. The basic principle of the Code is that each field should independently cover its own needs for Step I and at least part of Step II. Each sector club should be capable of independently covering the remainder of Step II and all of Step III.

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*By Kai Killerud, Director, Office of Safety, Statoil, Norway.

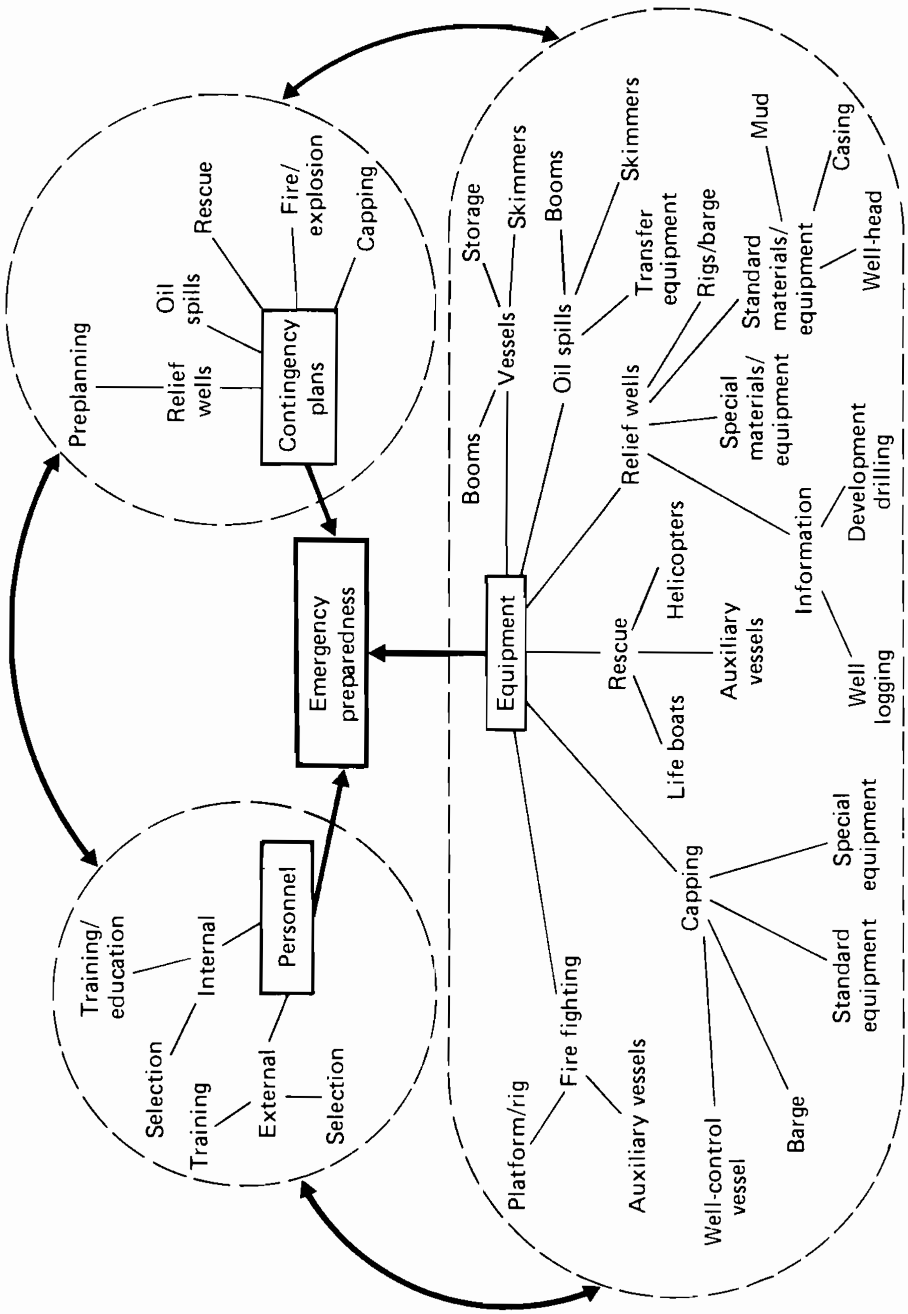

FIGURE 8.4.1 The main elements of emergency preparedness.

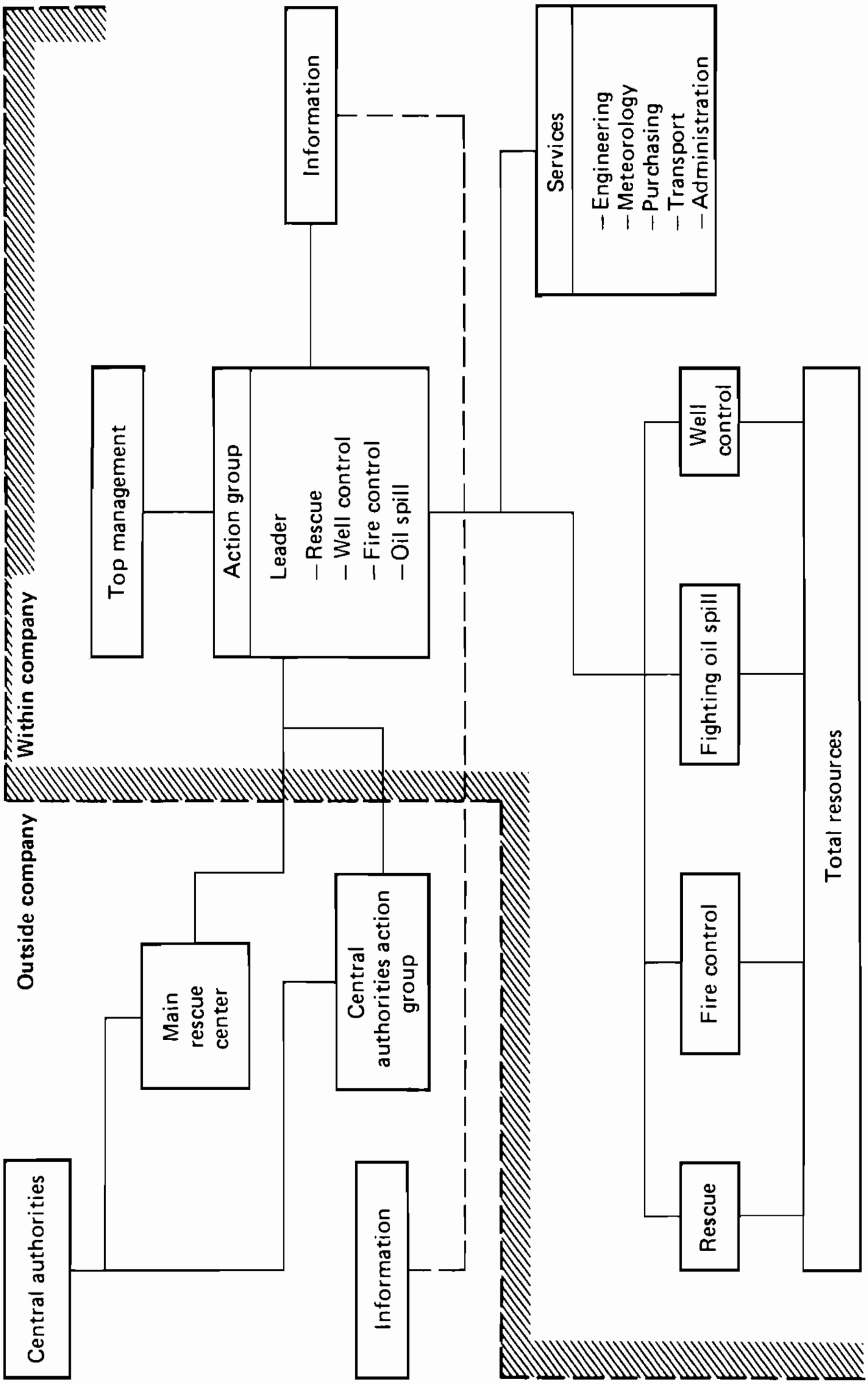

FIGURE 8.4.2 The overall organization of the Statoil contingency plan.

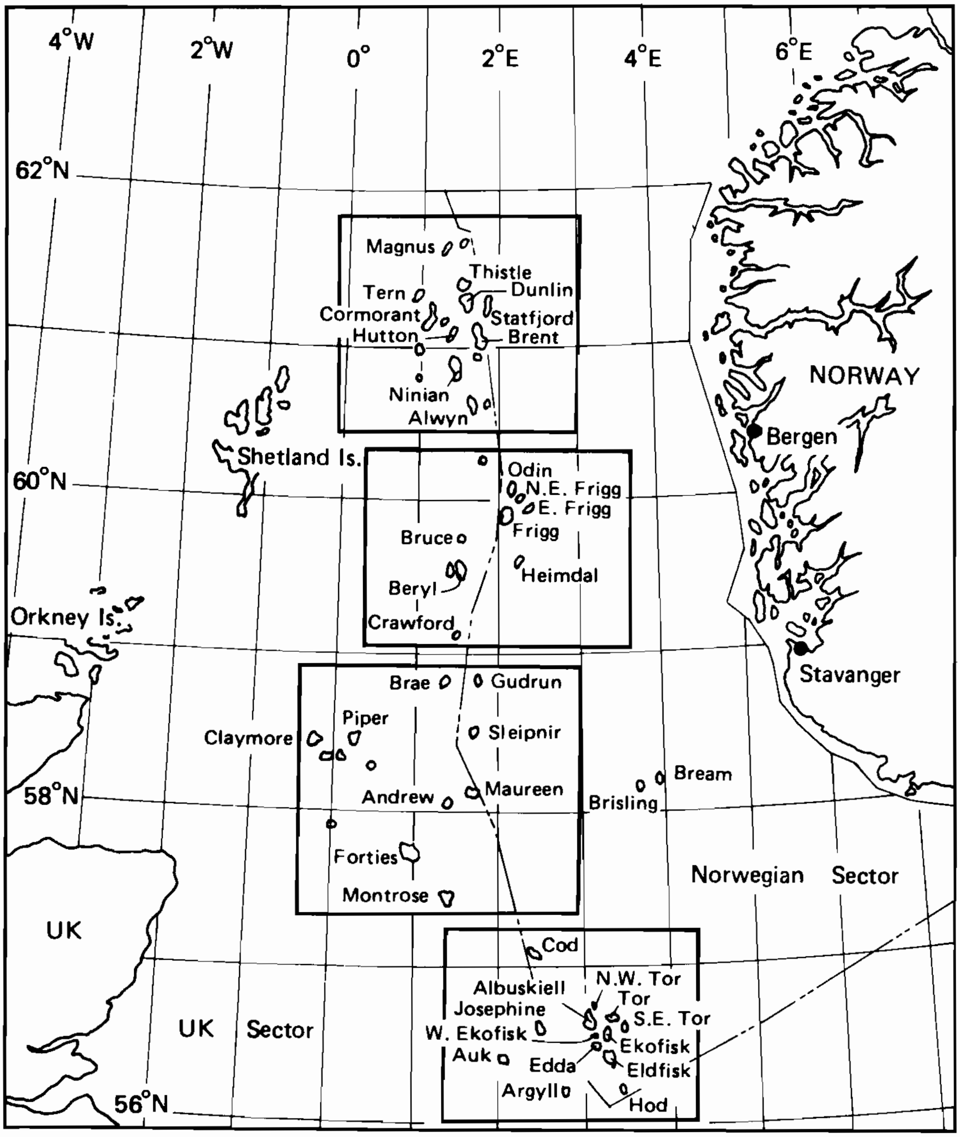

FIGURE 8.4.3 The NSOC–N/UKOOA emergency-preparedness plan: location of the four sector clubs involving both Norwegian and UK fields.

TABLE 8.4.1 Estimated effects of evaporation, natural dispersion, and mechanical clean up on a North Sea oil spill: percentages of oil remaining after various stages.

Stage	Wave height (and corresponding wind speed[a])			
	Low (2–3)	Medium (4–5)	High (6)	Very high (⩾ 7)
Original spill	100.0	100.0	100.0	100.0
Evaporation (day 1)	70.0	65.0	60.0	50.0
Primary clean up	21.0	32.5	42.0	50.0[b]
Evaporation (days 2–6)	16.8	27.6	37.8	50.0
Natural dispersion (days 2–6)	9.9	12.3	9.0	8.4
Secondary clean up	5.9[c]	8.6[c]	7.6[c]	8.4[c]

[a]On the Beaufort scale.
[b]No clean up attempted in very high seas.
[c]Percentage of original spill which arrives on the beaches.

The Code of Practice and Plan also contains information on the resources which should be available during an emergency, such as drilling rigs, vessels (for fire fighting, well control, hospital purposes, cleaning up oil spills, etc.), and other equipment such as mud pumps. As an example, when the Statfjord field is fully developed it is intended to have the following vessels at its disposal: two for evaluation and hospital use which can double up as fire-fighting vessels, two additional vessels for fire fighting alone, and one ship for well control.

Equipment for Fighting Oil Spills

Statutory requirements call for the provision of equipment that can pick up 8,000 tons per day; this equipment must be capable of operating in wave heights of 2.5–3.0 m and able to be mobilized within 24 hours of the beginning of the emergency. In practical terms these requirements translate into the following equipment. Twelve vessels are needed to control booms, six are required for the skimmers, and one other vessel acts as the command and coordinating center; in addition, a number of tankers are needed to carry away the oil collected. Other equipment required includes approximately 3,000 m of booms, six to eight skimmers, and the various pumps and fittings needed to transfer the oil to the tankers.

The specified meteorological operating conditions of 3-m wave heights and 13-m/s winds are, on average, only exceeded for 15–20% of each year in the North Sea.

Table 8.4.1 estimates the approximate efficiency of the system described above, under average North Sea conditions. It shows the relative contributions which can be expected from evaporation, natural dispersion, and mechanical clean-up methods, and concludes that a fairly constant 6–9% of the oil spilled may be expected to reach the beaches, regardless of the weather conditions.

Discussion

Some authorities feel that the assumptions used in developing Table 8.4.1 are too optimistic all round and that significantly higher waves and wind speeds should be expected.

This is a real problem. On the one hand it is unrealistic to take all the figures to their worst-case extremes (even though fisheries' interests would certainly prefer a worst-case analysis); even in winter, wave heights are less than 3 m for almost 80% of the time, but when the waves do get too high it is virtually impossible to collect any oil. On the other hand the study of very extreme cases is under way in order to ensure that the equipment used collects as much oil as possible from the sea before damage is done. The philosophical problem for a regulator is to decide whether to inform politicians of the worst possible outcome of an accident or to restrict the advice to a "most realistic" case. Finally, it is noted that a list of tankers available for storing spilled oil is maintained.

9 POLLUTION CONTROL

A.D. Read, A.J. Flikke, Eric B. Cowell, Lars Føyn, R. J. Morris, and David W. Fischer

9.1 OIL-SPILL CLEANUP ARRANGEMENTS IN THE OFFSHORE OILFIELDS*

This section, which has been produced by the UK Departments of Trade and Energy in consultation with the UK Offshore Operators' Association (UKOOA), deals with contingency planning for oil spills by offshore operators, and the nature and extent of government involvement when spills occur.

Primary Responsibility for Action, and the Role of the Government

The Operator's Responsibility

It is widely held, both in the UK and elsewhere, that the polluter should pay for the cost of cleaning up any spill. The UK government goes a stage further and maintains that the primary response role should rest with the polluter whenever this is reasonably practical. It is accepted that in the case of tankers, which make long journeys past the coasts of many countries, it would not be reasonable to expect shipowners – individually or collectively – to provide and maintain the worldwide organization that would be required to deal with spills wherever they might occur.

In the case of offshore oil operations off the UK coast, however, the potential source of a spill is localized and there are good communications and logistics facilities connecting the installations with the mainland. There is also, to a great extent, a pooling of interest within the UKOOA. Thus, it becomes a practical proposition, given advance preparation and planning, for the operator to fulfill the requirement of dealing with any spills of his own making. Much of this preparatory work is already in hand.

It follows, of course, that if the response is to be meaningful, the operator must have foreseen the contingency of a spill, drawn up an organizational and operational plan for such an event, trained the personnel concerned, and provided or have access to the necessary equipment and other resources. These aspects will be dealt with more fully later.

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*By A.D. Read, Department of Energy, United Kingdom.

The Role of Government

Assistance to Operators. Government experience in dealing with oil spills from tankers suggests that it would be difficult to justify the level of expenditure necessary to provide the resources required to deal with the "maximum credible incident," such as, in that field, the collision of two loaded VLCCs (Very Large Crude Carriers) with several tanks opened to the sea. If such an event were to occur, the government might if necessary look to industry or to its partners in the Bonn Agreement to augment its resources.

In a similar way, whilst an offshore operator must equip himself adequately to deal with the maximum size of spill, he may reasonably expect, having regard to the nature and scale of operations at his installation, that a situation may arise that will outstrip his capability. (UKOOAs current facilities are calculated to be capable of cleaning up about 2,000 tons of oil per day for eight days.) In such an instance, government would look favorably on any request for assistance.

It is likely that, by the time such a situation has developed, the spill will already have been reported to government as required, and the channel of reporting will offer the best means of requesting assistance. No doubt as a practical move, an operator faced with a situation beyond his immediate capability would call on the resources of other operators, of UKOOA, and possibly of the North Sea Operators' Clean Seas Committee, as appropriate. It should be borne in mind that the Department of Trade oil-spill cleanup organization is oriented to spills that threaten the coast, and operations well out to sea could pose problems, e.g., in terms of response time, replenishment, etc.

Protection of the Coast and Seabirds. The Department of Trade has been given the responsibility of dealing with oil spills at sea that threaten to cause major pollution of the coast, or to harm important concentrations of seabirds. In no way does it see this role as derogating from the primary responsibility of offshore operators to deal with spills from their own installations. However, it reserves the right to take action in fulfillment of its responsibility – and to recover the cost thereof from the responsible operator – should it form the opinion that the action of the operator is, for whatever reason, likely to prove inadequate. The department will, of course, confer with the operator in the first place and will, so far as possible, act in concert with him. Protection of the coastline becomes increasingly significant the nearer the installation is sited to land, particularly if the stretch of coastline in question is sensitive from the point of view of wildlife as well as amenity.

Major Spills. An extreme situation, such as a continuing release of oil following a major blowout, is of great interest, both to the public and to parliament. The spillage would no doubt be looked upon automatically as a menace, and it would become politically impossible for government to refrain from taking an interest in the cleanup operation. This is not to say, however, that the government would necessarily take charge. The circumstances prevailing at the time will dictate the degree of involvement, which may range from regular monitoring of the cleanup operation to assure itself that all reasonable steps are being taken, through assistance, to assuming control. Examples of such assistance are the provision of additional cleanup resources, or of aerial surveillance. The possibility of government involvement in this manner should not, however, dissuade the operator from providing the initial, full response to the spill.

Contingency Planning by Offshore Operators

Background

In order to meet his responsibility to deal adequately with spills of his making, an operator must have in readiness a viable contingency plan, backed up by the necessary resources. To ensure compatibility between the plans of different operators and of the government, and to assure the government that the degree of preparation and of response capability is adequate, operators have been asked to submit their plans to the Departments of Energy and Trade for examination.

Regulations

The preparation of such plans is required by the Offshore Installations (Emergency Procedures) Regulations 1976, which apply both to established fixed offshore installations and to mobile installations. They require every manned installation to carry an emergency procedure manual specifying the action to be taken, *inter alia*, in the event of a leak or spillage of any oil or gas [Reg. 4(1)(c)].

The scope of the regulations extends [Reg. 4(3)(c)] to action to be taken by persons on land or on other installations, and so covers all aspects of an oil-spill contingency plan. In addition, the Secretary of State may "upon demand" require a copy of this emergency procedure manual to be furnished to him [Reg. 4(6)]. Regulation 13(1) makes any contravention of the regulations by the installation manager, the concession owner, or the owner of the installation, as the case may be, an offence punishable by fine or imprisonment, or both.

Submission of Plans

Last summer the Department of Energy approached the 54 designated operators to whom Petroleum Production Licenses had been granted and asked them to submit their plans for examination. Contact is now maintained with 38 of the companies. Those excluded have either given up their licenses or have no immediate plans to drill. Drilling for some of those remaining will be undertaken by other companies, and those companies' contingency plans will cover the license holders. The department has so far received plans from 26 companies. Of the remaining 12, two have been promised as soon as possible and six are to be submitted when drilling is contemplated. (Four companies have not yet offered plans.) Plans have thus been received from all companies actively drilling in the UK sectors at this time.

Scope of Plans Received

The nature of the contingency plans received has varied considerably: several have been comprehensive documents; some have been the 1974 UKOOA guidelines (see below) "topped and tailed" (quite inadequate as a fullscale emergency operating plan); others have been letters or copies of internal memoranda which cover only the barest minimum. It may be that the companies whose submissions have been skeletal have nevertheless drawn up full procedures, but it is essential that officials see all these details, and not merely synopses.

Pipelines

While the Offshore Installations (Emergency Procedures) Regulations 1976 do not apply to submarine pipelines, pipeline operators are nevertheless being urged to prepare contingency plans similar to those for offshore platforms and to submit them for examination in similar manner. These plans should cover the action to be taken in relation to spills occurring at any point along the route of the pipeline, both well offshore and close to the coast. The remainder of the text applies equally to pipelines, as well as to other types of installations.

The UKOOA Plan

The UKOOA's Clean Seas and Emergency Services Committee published Oil Spill Contingency Guidelines in November 1974. A revised version is in preparation and is expected to be issued shortly. In addition, a comprehensive contact list of key personnel within government, local authorities, and other agencies was prepared about the same time by the Department of Energy and the UKOOA. This is presently being revised by the department. The UKOOA makes clear that it regards these guidelines as a framework, and it assumes that each operator will have his own operational plan with appropriate organizational structure, lines of communication, and provision of or access to adequate resources.

Part 1 of the 1974 Plan outlines the terms of reference and structure of the UKOOA, and describes the emergency action groups set up at Aberdeen and Great Yarmouth, and planned for the Celtic Sea. (Note that these action groups do not undertake the cleanup operation itself; their function is briefly described below.) Part 2 outlines action procedures and gives details of quick access to the use of shared services, in particular, spraying equipment and dispersant. It states that these jointly held resources provide an operator with the capability of dealing with most oil spills, as well as an initial means for tackling larger spills that can require providing further backup facilities. The plan goes on to describe the composition and location of the UKOOA units, the procedure to put the facilities to use, the location of the Department of Trade's stocks of dispersants, a list of international sources, specific details of the UKOOA bulk tank, and guidance on the use of dispersant. Through the North Sea Clean Seas Committee, a UKOOA member can also call on the resources held by other national operators' associations around the North Sea.

Limits of UKOOA's Responsibility

The UKOOA coordinators at Aberdeen are on call 24 hours a day to mobilize their resources and to make them available to the operator. Once alerted, the coordinator contacts the appropriate UKOOA holding company to arrange for the equipment, including tanks of dispersant, to be loaded onto the vessel, which has been arranged by the operator. Once this has been done, however, and the spray booms fitted, the responsibility for further action becomes the operator's.

The UKOOA function is therefore distributive rather than operational, and it is vital that operators acknowledge this by taking appropriate action to fill in the gaps. Also, they should make clear in their contingency plans how the UKOOA arrangements will be used within their own organizational structures. For instance, they should make clear that suitable manned vessels will be arranged to take on board the equipment and dispersants;

that the procedure to coordinate with UKOOA is understood by all relevant personnel; and that the crews of spraying vessels are/will be adequately instructed in the use of the equipment. If necessary, other companies' facilities and expertise could be deployed and their plans should make such arrangements clear.

There have been no returns to date from nonmembers of UKOOA. All the companies drilling at present are members.

Present holdings are based on UKOOA units. Each unit consists of one spray set complete with breaker boards and six lift tanks each containing 1,200 gallons of concentrate dispersant. These units are situated as follows: six in Lerwick, three in Aberdeen, one in Lowestoft, and two in Pembroke Dock.

Essential Elements of the Plan

The Appendix outlines the principal elements of an oil-spill contingency plan, and the action required to maintain an adequate state of preparedness as seen by government. The Appendix does not, however, seek to be fully comprehensive.

Appendix: Notes on the Principal Elements of an Oil-Spill Contingency Plan

Application

Regulations 3 and 4 of the Offshore Installations (Emergency Procedures) Regulations 1976 describe the range, scope, and application of a contingency plan.

Responsibilities and Training

The plan should be familiar to all those involved in following its procedures, and the allocation of responsibilities should be clearly set out and understood. The key operating staff should be trained in the control of a pollution incident and should have frequent opportunities for "refresher training." Simulated incidents should be devised from time to time to test the plan – in particular, its communications and decision-making elements – and the personnel. There should be provision for frequent updating in the light of the experience gained during these exercises, any actual incidents, and because of technical developments and personnel changes.

Reporting of Spills

All oil spills should be reported in accordance with company instructions. They must also be notified as quickly as possible to HM Coastguard (HMCG) by the most appropriate means of communication. HMCG will be responsible for relaying the information to the Department of Trade cleanup organization (presently through the appropriate principal officer). A report must also go to the Department of Energy (Petroleum Engineering Division) in accordance with the conditions attached to the production licenses. There should be provision for periodic situation reports to be rendered to the same addressees so that government may be kept fully informed of developments. This will reduce the number of enquiries, e.g., on behalf of ministers.

Contact List

An up-to-date directory (with means of contact throughout the 24 hours) is essential to any contingency plan. It should cover: all personnel involved at the installation; all company personnel – wherever located – who need to be informed; HM Coastguard and the appropriate principal officer (Department of Trade); and all other appropriate officials of government and interested agencies (but with clear instructions as to the circumstances under which any of these should be approached). For example, where an installation is so located that an oil spill will cause an immediate threat of coastal pollution, consideration should be given to the inclusion of appropriate local authority contacts.

Communications

The plan should make clear the best and then alternative means of effecting communications in relation to all of its parts.

Action Plan

All procedural steps from the discovery of an incident to its close should be mapped out, including callout procedures, and the means of early appraisal of the extent and consequences of the spill.

Surveillance of slick. Provision should be made for aerial surveillance of slicks, and it is recommended that a flight be arranged as soon as possible after the alert so as to determine the size and location of the slick as well as to assess its likely behavior.

Prediction of movement. Facilities should be available, either within the company's organization or by arrangement elsewhere, for the prediction of the likely movement of the slick. Provision should be made for obtaining appropriate meteorological and nautical information.

Treatment of slick. Clear guidance should be given on the appropriate method and scope of treatment, as well as on the procedure to be followed in order to seek outside assistance, should this prove necessary.

Consultation. Notwithstanding any general guidance that might be given as to the circumstances in which action or inaction might for the time being be appropriate, provision should be made for consultation at the time of an incident with the Nature Conservancy Council and with the Fisheries Inspectorate of the appropriate Fisheries Department (the Ministry of Agriculture, Fisheries and Food (MAFF) or the Department of Agriculture and Fisheries, Scotland (DAFS)) so that account may be taken of any particular circumstances then prevailing.

Public Relations

Oil spills from offshore installations are very likely to attract the interest of the news media. Experience has shown that these latter, if allowed free enquiry, can seriously inhibit the conduct of operations. It is strongly recommended that facilities (including accommodation and public relations personnel) be allocated for their reception and information in any incident that arouses their interest.

Resources

Full information should be given on the resources held by the operator for oil-spill cleanup operations, including any resources jointly held with other operators. This information should include the resources normally carried on the operator's standby and supply vessels. Many of these will be permanently loaded with dispersant and fitted with spray booms, etc. It will be expected as a minimum that standby vessels serving platforms close to shore and those using a tanker loading system will also be so equipped by carrying sufficient dispersant for at least one day's spraying. The plan should set down the procedures for activating or obtaining from elsewhere the required resources (e.g., equipment and dispersant) and for obtaining the use of manned vessels for spraying duties.

Any non-UKOOA operators should state their arrangements for gaining access to the necessary resources. Small operators should make clear any complementary arrangements they may have with other operators to assist (e.g., with organization, personnel, vessels, etc.) during an oil spill and its aftermath. They should also make clear how and to whom contact should be made.

Post Mortem

The action following an incident should include: the early restoration of all equipment used, including replenishment of dispersant stocks; and a survey of the incident itself and of the action taken to deal with it. This should determine how the contingency plan stood up to the test and what lessons have been learned for the future. These lessons should be reflected as necessary in appropriate amendments to the contingency arrangements.

Spills of significance are fortunately rare, but live experience is therefore sparse. It is accordingly recommended that operators make a brief report to the Department of Trade on any lessons learned above for dissemination to other operators.

9.2 THE REGULATORY APPROACH TO POLLUTION CONTROL*

The peculiarities of the North Sea compared to other oil-producing areas of the world are well known. Suffice it to say that, relatively speaking, the environment is very hostile, and that water depths and the sea conditions in the early stages of development pose some completely new problems. As far as construction work is concerned, it is probably true to say that pioneering work has been necessary but is now complete.

In terms of drilling and safety technology, the North Sea also presents challenging and difficult problems. It is well known that typical North Sea production zones in limestone or chalk are capable of production rates exceeding 25,000 barrels per day under present completion and operating conditions, and that these wells under blowout conditions could flow at a rate of 80,000–100,000 barrels per day. Closed-in wellhead pressures for these wells would be on the order of 5,000 psi or close to 350 kP/cm^2. In known sandstone reservoirs, under expected calculations, a flow of 50,000 barrels per day using 7-inch tubing string and appropriate back pressures are to be expected. With open flow through 9.625-inch casing to the atmosphere, the flow rate may exceed 100,000 barrels per day. Closed-in wellhead pressure is likely to be in the region of 3,000–3,500 psi or 200–250 kP/cm^2. Jurassic wells in sandstone formations are also known, but little infor-

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mation is as yet available. It is, however, significant to note that closed-in wellhead pressures are exceedingly high, perhaps on the order of 8,000–10,000 psi or 500–700 kP/cm^2. Availability of equipment with the appropriate working pressure (15,000 psi) is limited. In addition, the closing time for a blowing well may be as high as 100 days or more, if a relief well has to be drilled.

In summary, therefore, it may be said that environment and formation pressures emphasize the importance of safety aspects, and that the large flow rates to be expected during a blowout in the North Sea may create a pollution situation never before experienced offshore if appropriate measures are not taken. The discharges will, if the situation should develop, take place on the doorstep of some of the most important European harbors and in waters of significant fishing importance. The sanding up of a well, which could reduce the flow , in all probability will be quite slow, so that natural circumstances cannot be relied on to retard the expected flow rate.

The activity on the Norwegian continental shelf at the time of writing may be indicated briefly by the following facts: thirteen operators are registered; approximately 200 exploration wells have been drilled; some 50 wells are producing oil in the Ekofisk area with a final total of 100–120 wells expected; at Frigg some 25 wells are presently producing gas; Statfjord A began producing in 1980 and will reach a total number of 42 wells; and two more platforms are planned.

It is unnecessary to give a lengthy explanation of the events leading to an open-hole blowout offshore. Suffice it to say that risks are involved during certain phases of drilling, completion, and overhaul, and that serious accidents can also take place during normal production. Briefly speaking, accidents may be grouped as follows: blowout from an exploration well being drilled from a floating rig or drill ship, and blowout from one or more wells on a fixed installation caused by accident during drilling or workover, gas explosion, fire, or damage to structure.

While accidents under the first group will lead to an underwater leakage that may only be stopped by drilling a relief well, the second group of accidents may possibly be cured by capping the blowing well or wells. Relief-well drilling will take on the order of 100 days, while capping may take a considerably shorter time. Successful capping is, however, to a large extent dependent on the surrounding conditions. Fire and deterioration or collapse of the structure may cause great problems and necessitate the drilling of one or more relief wells.

Discussing oil activities and risk elements naturally suggests the question of what kind of situation would result should a large-scale accident occur on the continental shelf of one of the North Sea countries if the oil is not contained and removed. In Norway considerable thought has been given to this problem, and several measures have already been implemented in order to counteract it. Practical research and experience from the Bravo accident has proved that North Sea oil is broken down quite rapidly, and that only small amounts will ever reach the shoreline.

A Norwegian institute has made theoretical predictions, shown in Table 9.2.1, which indicate that only 2–5 percent of the oil will reach the shoreline. This table is partly based on the recorded wave heights noted in Table 9.2.2. Other calculations indicate the drift-times to shore shown in Table 9.2.3. Drift models indicate that spills in the central part of the North Sea will threaten the west coast of Denmark to a large degree and southern Norway to some extent, while spills in the northern areas will drift mainly towards the west coast of Norway. All calculations indicate that little or no oil will reach UK shores.

TABLE 9.2.1 Calculated times (days) for oil discharged on the Norwegian continental shelf to reach the shoreline[a].

From location	October–March Fastest drift-time	October–March Average drift-time	April–September Fastest drift-time	April–September Average drift-time
Ekofisk (October 1972–April 1977)	10	17	12	20
Statfjord (October 1972–April 1977)	5	10	8	17
Haltenbank (April 1973–July 1977)	4	7	6	12
Tromsøflaket (April 1973–July 1977)	5	10	7	9

[a]Calculations performed by the Norwegian Meteorological Institute, based on winds and currents in the areas.

TABLE 9.2.2 Percentage of period when wave heights are below given limits.

Period	Place	Under 1.5 meters	Under 2.5 meters	Under 3 meters	Under 4 meters
January	Ekofisk	24	49	61	80
	Haltenbank	23	49	60	76
	Statfjord	16	36	48	70
	Tromsøflaket	30	59	70	84
July	Ekofisk	39	70	81	93
	Haltenbank	45	75	85	95
	Statfjord	30	61	73	90
	Tromsøflaket	52	77	87	95
Yearly average	Ekofisk	29	59	71	87
	Haltenbank	32	62	74	86
	Statfjord	22	47	60	79
	Tromsøflaket	40	69	80	91

TABLE 9.2.3 Calculated amounts of oil that would reach the shoreline during blowouts at Ekofisk and Statfjord.

	Most favorable month		Least favorable month		Average oil reaching shoreline
	Percent[a]	Tons[b]	Percent[a]	Tons[b]	(% per month over the period)
Ekofisk	0	0	5	12,000	1.4
Statfjord	2	4,800	6	14,400	4.0

[a]Amount in % of total discharge reaching shoreline during one month.
[b]Calculation based on a discharge of 8,000 tons of oil per day in 30 days. Evaporation and natural dispersion included.

Under the circumstances there is little reason to believe that massive amounts of oil from the central parts of the North Sea, such as during a tanker accident will be encountered in any areas. Most probably the oil will hit the coast in scattered places as an emulsion and in patches, requiring mobile cleanup forces and a good surveillance system to give advance alert. Large spills from the northern UK and Norwegian fields will, however, present a more serious threat to the west coast of Norway, owing to the prevailing westerly winds and the direction of the currents (from south to north) that will distribute the oil over very large areas.

Even though only a fraction of the discharged oil is expected to drift ashore, the total amount of oil will be of importance if an incident of long duration should occur. Furthermore, extremely large amounts of oil will be mixed into the water column, with as-yet unknown effects on and damage to marine life. For this reason, there is strong opinion in Norway that maximum efforts should be exerted to reduce the risk element by proper regulations, inspection, and control, and to build up an efficient system for the mechanical removal of oil from the sea. Since the control side has already been dealt with, no further comment will be made but the question of pickup of oil from the sea needs discussion.

First efforts to establish a mechanical system for picking up oil at sea were started three years ago. Studies carried out at that time showed that no equipment suitable for use in the North Sea was available. The only equipment of any interest was a very large boom built by Exxon for the Santa Barbara Bay, and a pickup system owned by the Clean Gulf Association consisting of a 500-ton barge with a boom arrangement delivered by a Canadian firm. It was soon agreed that the Exxon arrangement was too impractical in size and operation, while the Clean Gulf system, though interesting in principle, could not do a useful job in the North Sea unless extensively modified. Having come to this conclusion, requirements on the operators for mechanical pickup equipment were temporarily postponed while work went ahead with establishing an oil-pollution control system for the Norwegian coastal areas.

The work also concentrated on an emergency system for larger shipping accidents and on action management and alert procedures. In 1975–1976 US \$2 million was invested in equipment for six coastal depots, and in 1976–1977 another US \$10 million was granted by parliament for the purchase of four special oil-recovery vessels and heavy booms and skimmers for an additional six depots. During all negotiations a point was made of informing industry about the increased demands for offshore containment and collection systems. The technical specifications were gradually strengthened, and industry seemed to respond. By 1976, therefore, it was felt that equipment was beginning to be available that could perform with some success under moderate conditions, and in September of that year, operators were requested to come up with a proposal for a system that could remove oil from the sea in two-meter waves from a blowout of 8,000 tons per day. This proposal was under evaluation for approval by the Norwegian State Pollution Control Authority, and some of the equipment was under practical testing when the Bravo accident occurred in April 1977.

In accordance with Norwegian regulations, the oil companies have accepted an unlimited liability for all damages caused directly or indirectly by their activities. They have also accepted that an up-to-date pollution-control system for larger oil spills should be available, and that this system should be subject to approval by the environmental authorities. For practical reasons the operating companies wanted to build up this system jointly under the North Sea Operators Committee, and this arrangement has been approved by the authorities on the basis of providing equipment for two simultaneous large-scale blowouts in different areas.

The use of the equipment is based on the philosophy that each individual operator is responsible for his own spill, and that equipment is made available to him free of charge when needed. An operations plan has been worked out jointly, but each operator has to adjust this plan to his own internal organization and to make it an integrated part of his contingency plan. The operators also have worked out a common code of practice on how they are going to assist one another in an emergency in terms of special equipment, vessels, experts, and other personnel.

The system under development today by the operators on the Norwegian shelf is based on conventional concepts. Basically, it consists of 3,000 meters of heavy boom and 6–8 large-capacity skimmers. When fully implemented, six dedicated and special equipment-supply vessels will form part of the system, all capable of loading 1,000–1,200 tons of oil or oil emulsions. A well-prepared tanker shuttle for bringing the oil recovered to shore will also be part of the system. The concept is to use the booms, in lengths of 300–500 meters, downstream from the blowout and to position the skimming vessels at the bottom of the U-shaped sections.

In connection with drilling north of latitude 62° N, a similar system is under final planning and implementation. It is not possible to avoid the question of whether the system now under implementation is realistic. Of course, no such guarantee can be given, but, so far, this system represents the best mechanical system that it has been possible to produce, and it is felt that this will do a useful job under moderate conditions.

It is recognized that some drawbacks exist: the system is very complicated to operate in terms of the number of vessels maneuvering in a limited area; operation becomes increasingly complicated in waves exceeding 1.5 meters; reduced visibility from darkness or fog will seriously complicate operations and reduce efficiency. By consulting Table 9.2.2, and considering conditions of reduced visibility, an assessment of the efficiency of the system can be made. Nevertheless, the problem is of such a nature and magnitude that it simply cannot be left there. This is merely a first step and the development of new equipment must continue or special arrangements be made on the platforms to prevent oil from reaching the sea. In an age when we can send people to the moon and back, it is inconceivable that the problem of oil pollution from a blowout cannot be overcome. It is not so much a question of what is possible, but rather of the amount of money made available to find a solution.

It should be remembered that, at present, there is an overemphasis on oil coming ashore during a blowout, rather than on consideration of the long-term effects of oil in the marine environment; the pickup systems proposed so far are more of a burden than a help; and there were no complaints from fishermen about oil around the Bravo accident area.

9.3 ENVIRONMENTAL EFFECTS FROM THE OPERATOR'S VIEWPOINT*

This section will concentrate on the response of the ecosystem to oil spills rather than the reactions of industry or government to the accidents.

Some Common Misunderstandings

It is certainly not true that all oil spills are equally damaging. Every spill is an individual event and the biological effects vary according to many factors, including the time of day or season, the geographical location of the spill, the weather at the time, the quantities of water present, and the amount and type of oil spilled. It is of particular importance to note that refined products such as diesel fuel, "No. 2 fuels," etc., are generally more biologically damaging than are crude oils or heavy fuels, except to bird populations.

It is often thought that the most damaging impacts of oil spills are felt by seabirds. However, most seabird populations are fairly robust. The impacts on these populations are complex and depend upon the locations and timing of the spills as well as the reproductive capacity of the species concerned. Existing natural stresses or tendencies, including population cycles, are of great importance in determining the overall effect. Except in the case of rare or endangered species, cleaning seabirds may satisfy peoples' emotions but does little to help the bird populations affected. Bird cleaning can in many instances prolong suffering without benefit to the birds. To make better use of the concern undoubtedly felt by the public, amateur efforts could perhaps be directed toward methods of improving breeding success, for example the creation of new and improved nesting areas. When looking at the ecosystem as a whole, the point should be made that the number of individual birds killed is less important than any underlying alteration or destruction of the ecosystem role of the species concerned.

One commonly-held view is that oil is a uniform substance that is always equally damaging. This is of course a great over-simplification. Oils have differing chemical and physical properties and can differ greatly even when they share common geographical origins or are obtained from the same field. Changes, some of them very rapid according to the nature of the oil, local weather conditions, the state of the sea, etc., can in fact occur after spillage.

Laboratory experiments on the toxicity of dispersants often have little relevance to the real world. These experiments frequently involve the exposure of marine organisms to dispersants for long periods, for example 48–96 hours, whereas locally toxic levels in nature may only be maintained for 2–3 minutes. Even in the case of the *Torrey Canyon* incident, where outdated toxic dispersants were misused on a massive scale, no permanent damage was recorded and fish catches afterwards were not affected. There is no concrete evidence that dispersants significantly add to the risks incurred by marine life during and after blowout incidents. Indeed, if correctly used, dispersants can minimize ecological side-effects.

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Recommendations

Every effort should be made to prevent oil from reaching coastlines, since dilution effects and other factors are adverse in shallow coastal areas. Somewhat surprisingly, it is not always appropriate to clean oiled beaches, since in many situations cleanup techniques can be more damaging than the oil itself. Oil-spill relief coordinators must not always give way to public pressure for total cleanup, but should consult ecologists to ensure that the proposed response is appropriate for the local environment. Dispersants should not be used in areas of restricted water exchange, especially freshwater lakes, rivers, tidal marshes, and shallow seas close to fish-spawning grounds. The documentation of ecologically sensitive areas should be part of all contingency planning. Decision makers must beware of giving in too easily to public demands; when necessary, they must have the courage to say that doing nothing can sometimes be better than increasing damage through the use of inappropriate cleaning methods. There is a need for cooperative field work on the best methods of cleaning oil spills. As stated above, laboratory-based toxicity tests are often not useful in predicting real-life oil-pollution effects. Finally, more research is needed on the mechanisms by which oil becomes incorporated into sediments; the role of dispersants in preventing or encouraging the phenomena involved needs further investigation

Discussion

Given the potentially large scale of oil accidents (for example, an oil blowout of 25,000 tons per day for 100 days), a pollution-control system based on chemicals alone does not seem adequate. A blowout on this scale would almost certainly deposit oil on the coast, regardless of the nature or efficiency of the pickup system used or whether total reliance were placed on mechanical pickup methods. Furthermore, even if a mechanical system of 90 percent efficiency existed, it would be too costly to have one such system (or vessel) standing by continuously at every potential blowout site; therefore, one returns to a comparison of the costs and risks inherent in each method used.

When discussing the use of particular methods, the differing cleanup philosophies and geographical locations of the various North Sea countries must be considered. For example, chemically dispersed oil from UK fields can arrive in the Norwegian sector as soon as two hours after an incident because of the prevailing currents; thus, in a sense, the UK never has to live with the results of its decision to use chemicals to disperse the oil. However, forecasts based on dispersion models show that under most circumstances no oil will reach the coast.

Aerial dispersant spraying offers great promise for a rapid response on a large scale which can then be followed up by spraying from surface vessels. At the time of writing, however, some technical problems remain so that the technique must still be considered to be under development. In practice, one can never treat an entire oil slick with dispersants so it is usually more a matter of deciding which areas are to be protected. It will not generally be possible to pick up or treat most of the oil spilled but natural processes will deal with very large quantities through evaporation and dispersion.

To conclude, the most satisfactory basis for dealing with the effects of blowouts seems to be a combined approach, involving chemical, mechanical, and natural cleanup processes and controlled by expert judgments on which methods are most appropriate for each of the areas affected.

9.4 OIL EXPLOITATION – A DANGER TO FISHERIES?*

The North Sea fisheries, or rather the northeast Atlantic fisheries, are some of the most important in the world. With an annual catch of approximately ten million tons, of which three million come from the North Sea, these areas contribute to the total world fisheries catch of around seventy million tons in a very considerable way. During the last ten years the oil activities in the North Sea have also demonstrated this area's activity as an important oil production site. With both valuable fishing grounds and oil fields, the North Sea can become an area of conflict between those exploiting two valuable resources: fish, which are renewable, and oil, which is a nonrenewable resource.

Although there had not been any major pollution in the North Sea from oil activities until the Bravo accident, the problems of oil damaging the fishery resources have been and still are an important concern for Norway. These problems have been dealt with in several parliamentary white papers.

In addition, fisheries are particularly important in connection with the plans for extension of oil exploration on the Norwegian continental shelf north of latitude 62° N. The fear of conflict in these more northern areas has been more pronounced than in the North Sea because they are more vulnerable to pollution damage. Some of the northeast Atlantic's most valuable fish stocks have their spawning areas and migration routes along the Norwegian coast. Therefore, both scientific and political concern have been focussed there.

It is appropriate here to give a brief explanation of the behavior of oil in the sea and its effects on marine life, and in particular fishery resources. Crude oil is composed of thousands of different hydrocarbon components. The composition of a crude oil reflects its place of origin and this composition determines the potential damage to the environment. The oil components and their degraded products have different levels of toxicity, degradability, and solubility in seawater. They are, to various degrees, absorbed by living organisms. Some of the oil components are unlikely to be harmful, while others, in particular the aromatic hydrocarbons, are known to be harmful. When oil is spilled on the sea, it is exposed to physical, chemical, and biological action. The lighter oil components evaporate and some oil is removed as the wind and waves whip the oil into droplets, the resulting aerosols being blown away. In addition, some oil components dissolve in the water, some are whipped into the water as small droplets, and some form water-in-oil and oil-in-water emulsions. In this way oil is broken down physically and the products subjected to biological and chemical activity, which in turn break them down further.

The movement of oil on the surface of the sea is mostly dependent on wind forces. As the oil is mixed down into the water, the movements are further influenced by permanent oceanic and tidal currents. Absorption of oil in the water to form particles may give it a distribution somewhat different from that predicted from prevailing wind and current directions. The physical influences on the oil described above will remove it from the site of spillage and from the water surface.

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When chemicals are used to disperse the oil, all oil components are moved down into the water and interact with marine life. As the use of chemicals is most effective during the first few hours after the oil has reached the sea, the operation of natural forces, such as evaporation, and the formation of aerosols by wind drift will be seriously inhibited and only a fraction of the oil that would have been removed in the absence of chemicals will actually be so affected. Evaporation removes an estimated 50% of Ekofisk oil from the sea surface if the oil is simply left alone.

Oil and oil components have little or no effect on marine life until they move down into the water; consequently, those processes that remove spilled oil from the sea surface without interfering with the water layers beneath the surface will cause least disruption to marine life. Therefore, the Norwegian fisheries authorities have strongly recommended the use of mechanical oil-removal equipment for oil pollution. This policy is based primarily on the fact, as stated above, that damage to fisheries from oil pollution is most pronounced when the harmful components of the oil are distributed below the surface layer of the sea where sensitive marine organisms are to be found.

The sensitive organisms, the plankton, include the primary producers, the phytoplankton, the next steps in the marine food chains, the zooplankton, and the youngest stages of fish, eggs and larvae. All drift more or less passively with the water masses and thus are vulnerable to pollutants within the same body of water.

Phytoplankton are sensitive to oil; the concentrations at which fatally toxic effects or reduced production capacity have been observed are as low as 0.1 microliter of oil per liter of water. During the Bravo accident, a significant reduction in primary production in the vicinity of the Bravo platform was found.

Some species of zooplankton are known to accumulate oil hydrocarbons without harm, but toxic effects have been observed in other species at concentrations of ten microliters of oil per liter of water. Investigations during and after the Bravo accident showed that some environmental conditions, i.e., an early spring with little biological activity, caused a scarcity of zooplankton in the area; but, where fresh oil was observed, there were also effects on the zooplankton.

As mentioned above, it is the youngest stages of the fish life, eggs and larvae, that are most vulnerable to oil pollution. However, the literature gives various figures for the concentrations that affect fish eggs and larvae. Depending on the actual species, fatally toxic effects have been observed for concentrations as far apart as 200,000 microliters to 1 microliter of oil per liter of water. These figures probably do not give a realistic picture of the real concentrations as they are mostly based on volumes of oil added to the water and not on the concentration of oil in the water. Chemical analysis of the water gives the correct concentrations at which the effects are observed. Based on such analyses, effects on the development of capelin eggs have been observed at 20–30 mg of oil per cubic meter of seawater (ppb), which is far below the figures quoted above.

The North Sea mackerel has its major spawning site in the area of the Ekofisk field. Since the mackerel eggs were floating close to the surface, there were fears that the oil from the Bravo blowout would damage this fishery resource, but fortunately mackerel spawning had not started at the time of the blowout and by the time it finally started the oil had dissipated.

A summary of the findings of the investigations on the Bravo accident stated that acute effects were small. Although sublethal effects cannot be excluded, the low concentrations of hydrocarbons in the water columns outside the immediate neighborhood of the platform, combined with the low availability of sensitive organisms, make it unlikely that any serious acute harm to the fishery resources occurred. It is evident that several factors account for this: mainly the high temperature of the oil on escape and the fact that winds and rapid surface spreading caused efficient evaporation of the most volatile and toxic compounds. Furthermore, unstable conditions in the water masses caused the effective dilution of dispersed and dissolved hydrocarbons.

So experience from oil pollution from the Bravo and other accidents seems to indicate that the fears of catastrophe to marine life from oil are exaggerated. However, small continuous oil spills from offshore oil installations are of concern because not enough is known about sublethal effects of oil on the different species and on marine communities, including interactions between them. Furthermore, oil is just one small part of total marine pollution, and therefore all other pollutants have to be considered to give a picture of the real "health" of the sea.

From the fisheries point of view, pollution damage to individual fish is of no particular interest. Concern is more with the effects on overall fishery resources; in other words, will the pollution harm the overall harvest of sea resources? A more realistic approach to the marine-pollution problem must take account of the real damage that might be suffered should the pollution coincide with spawning. Although nature itself takes a great toll, pollution may add to this to such an extent that the population of a particular species is significantly reduced and, as a consequence, the potential harvest of that fish stock is drastically diminished.

In Norway, where the fishery resources are a valuable part of the economy and form the very basis of existence for most communities along the coast, more attention will obviously be paid to eventual damages from oil exploration and exploitation than that likely in a country where fisheries play a less important role. This importance may be seen in the different approaches to combating an oil spill. The use of chemicals to disperse the oil will be viewed more favorably where public concern focusses on dead sea birds and polluted beaches rather than unseen organisms in the water, while physical methods will be in favor where fisheries have considerable economic importance.

Finally, consider the question posed in the title: is oil exploitation indeed a danger to fisheries? Some of the important points have been considered above. But the major problem to Norwegian fisheries up to now has come from a so-far unmentioned hazard – obstacles on the seabed caused by laziness in dumping unwanted tools and other equipment on the bottom instead of bringing them ashore for disposal. As regards oil pollution itself, the different authorities regulating oil activities must pay much more attention to advice from marine biologists as this advice will at least help to prevent unnecessary pollution.

Accidents, although still feared, even with the worst possible coincidence of migrating and spawning fishes, weather conditions, etc., will only damage the population of the species for one season, not the total fishery resources. Therefore, with some reservations, the original question can be answered in the negative.

9.5 EFFECTS OF POLLUTION CONTROL ON MARINE ECOSYSTEMS AND SPECIES*

Decisions must be made on the treatment of oil spills as and when they occur. However, as a result of limited scientific data, those decisions that include any element of environmental risk assessment are at best educated guesses aimed at minimizing the overall ecological damage.

The object of environmental risk assessment is to weigh the potential effects on the normal ecosystem of a particular perturbation. A complication to any such assessment is that sometimes in lessening one risk, another is increased, thus creating problems for decision-makers. In the marine environment there are a number of ecosystems and species groups that can be affected in a variety of ways by an oil spill and its treatment. Without attempting to cover all the potential variables, the following factors certainly need to be major considerations for any environmental risk assessment.

Major Factors in Marine Risk Assessment

Littoral Ecosystem

Of all the marine subecosystems, this is probably the best known, because it is the easiest to sample quantitatively. Over the years many research workers have built up a considerable amount of data on the effects of natural and nonnatural perturbations on a range of littoral ecosystems. However, there is still much to be learned. Littoral ecosystems are designed to withstand a number of large, natural perturbations, such as dehydration, temperature extremes, wave exposure, and fluctuations in available oxygen. Ecosystems that can survive such natural stresses might be expected to be better equipped to cope with other stresses such as oil pollution than less naturally stressed ecosystems. Alternatively, it could be that ecosystems already naturally stressed are less able to withstand additional stress. The beaching of floating oil and its dispersal into the water column close inshore are likely to be the major risks to the littoral system arising from an oil spill. Recent work by the Marine Biological Association (UK) suggests that, ten years after the *Torrey Canyon* oil spill, the effect of the beached and dispersed oil on parts of the Cornish littoral ecosystem can still be seen.

Benthic Sublittoral Ecosystem

This is an extremely important part of the overall marine system, and benthic ecologists have put much effort into overcoming the problems of sampling. Reasonably reliable grabs are now available that can take a quantitative sample, even in deep water. However, a large sampling program must be mounted before a usable baseline can be established for any particular benthic area. Hence, limited data are available on long-term changes within benthic ecosystems as a result of seasonal or other less predictable effects. The sinking of oil into sediments poses the most obvious threat to the benthic ecosystem, although the

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potential effects of soluble or dispersed oil in the water must be considered, especially in areas of restricted circulation.

Estuarine and Salt-Marsh Ecosystems

Although considered as separate entities, these systems are composed of closely knit littoral and sublittoral ecosystems with many complicated trophic interrelationships. They experience many of the natural stresses common to littoral and shallow-water sublittoral ecosystems, together with large salinity variations and many changes in other chemical properties of the water, owing to the complex reactions that occur in the freshwater/seawater mixing zone.

The beaching of floating oil, its sinking into sediments, and its dispersal in inshore water columns all pose potentially serious threats to these ecosystems. In addition, the soft, unconsolidated nature of sediments in these areas can result in penetration of oil into underlying sediments. If this occurs, long-term chronic pollution over a period of several years is likely owing to the slow leaching of the oil back out of the deeper sediments and into the surface sediments and overlying water.

Midwater Ecosystem

This is a three-dimensional system involving many different trophic levels. It is by far the most difficult of all marine ecosystems to understand. Several research groups have spent a number of years attempting to examine just the major variables of such systems and are still only able to make very general statements about their behavior.

Midwater ecosystems exist in fairly stable environments (i.e., stable salinity, temperature, available oxygen, nutrient levels, etc.). Even relatively small changes in certain environmental parameters can result in significant ecological changes. The problem is how to quantify these changes. The sampling technique (i.e., net design, method of towing net, speed of towing, time and depth of haul) is extremely critical. It is unlikely that any net takes a wholly quantitative sample, but even for relative comparison of samples it is vital that the fishing technique does not vary. Therefore, clearly, if changes occurring as a result of natural variations cannot be quantified, the potential impacts of nonnatural perturbations can at best only be subjects for guesswork. Statements are regularly made that there is no evidence of effects to the marine ecosystem from this or that pollution incident. Such statements are factually correct, but it is likely that, since these ecosystems are so difficult to quantify, no effects will be noted unless they are catastrophic. The solution, mixing, and dispersion of floating oil into the water column poses the major threat to midwater ecosystems.

Seabirds

Apart from oiled seabirds being a painfully visual and very emotive result of an oil spill, floating oil is a real threat to many coastal seabird colonies. Several research groups in the UK believe that even a relatively small oil slick at the wrong time and in the wrong place can result in large-scale mortalities to important breeding populations, which would have serious long-term implications for the survival of certain species. Migratory species are most at risk during their seasonal migrations, but inadequate data are available on seabird movements to be able to predict the start, duration, or route of these migrations reliably.

Pollution Control and Risk Assessment

What risk assessments can be made to aid decisions on treating oil spills? Obviously, if the floating oil can be removed from the sea surface mechanically, this will remove the threat to all parts of the marine system. Arrangements also have to be made for the safe dispersal of the recovered oil and oil emulsions, which, in the case of large spills, may amount to many thousands of tons. At present the UK does not believe that mechanical recovery can be relied upon as the sole method for oil-spill cleanup. Natural dispersion (mixing and solution into the bulk seawater), evaporation, and weathering of the floating oil at sea are considered to be the next-best "treatment," provided the floating oil does not threaten important offshore seabird populations.

Natural dispersion will result in raised levels of hydrocarbons in the water column under the oil slick. It is often difficult to measure such increased concentrations, as they quickly drop to the ppb level as the distance from the slick increases. Hydrocarbon levels in the ppb range are often below the sensitivity of water sampling and analytical techniques. Therefore, because hydrocarbons in the water column below an oil slick "cannot be detected," it does not mean that a significant raising of the normal background hydrocarbon level has not occurred. Chemosensory processes, which are believed to control many aspects of the behavior and interaction of marine organisms, almost certainly take place at and below the ppb level in seawater. Thus, the potential for ppb levels of hydrocarbons in the water to interfere with these complex and very important processes must not be ignored.

Effect of Pollution Control on Ecosystems

Better data are gradually being acquired on the fate and behavior of different types of oil at the sea surface so that more reliable predictions can be made on oil-slick movement. Such predictions are very necessary if the possible risks to inshore ecosystems or bird populations are to be gauged. If there appears to be a real threat to these systems and mechanical recovery cannot be relied upon, other methods of treatment must be considered. The UK believes that the use of dispersants in offshore areas is a valuable and necessary option in such situations. The decision that has to be made is whether the potential effects of the floating oil on the better known and visible ecosystems (littoral, shallow-sublittoral, estuaries, salt marshes, seabird colonies) are more serious than the potential effects of the chemically dispersed oil on the poorly understood midwater ecosystem. Such decisions have to be made quickly, because as the floating oil moves inshore into areas of shallower water, there is less capacity for diluting the dispersed oil. The UK believes that under these circumstances the chemical dispersal of the floating oil to deep water well offshore is generally the best environmental option, unless the offshore area in question contains important fish breeding grounds. However, it is clear that such decisions are essentially based on educated guesses about relative environmental risk.

Decisions on oil-spill treatment cannot be taken in the absence of economic considerations. Damage to a coastal area can be relatively easily quantified in terms of lost amenities, unemployment, loss of business, etc. The damage to offshore fisheries is less easy to cost. Thus, oil operators who eventually may face damage liability claims as a result of oil spills are likely to favor methods of treatment that minimize the most obvious and most easily costed damages. It is, however, necessary to ensure that such economic considerations do not totally outweigh environmental considerations.

9.6 ALTERNATIVE POSTURES FOR OIL-SLICK CLEANUP*

During discussions at the Workshop, five main approaches to oil-slick cleanup emerged. This section summarizes the most important advantages and disadvantages of each approach.

Mechanical Removal Only

The *advantages* of this approach are as follows. Under favorable operating conditions, the spilled oil can be totally removed. The method is politically visible, showing that "something is being done." It relies on a high degree of technological sophistication but is very effective near the shore in calm waters.

The *disadvantages* of the method are as follows. It is relatively ineffective in the open sea with wave heights exceeding 1.5 meters. Emulsified oil is extremely difficult to capture by mechanical means. Finally, an extraordinary effort is needed for the effective coordination of the vessels and personnel involved.

Chemical Dispersion Only

The main *advantages* here are that the method speeds the existing natural dispersion process and that it reduces the political visibility of the problem. Furthermore, it is more economical than mechanical cleanup methods.

The *disadvantages* of the approach are as follows. The effects of chemical dispersants on marine life in the open sea are still perceived as largely unknown, despite considerable research, and the use of chemicals in coastal waters can be dangerous. A very rapid response, with tons of chemicals readily available, is necessary if this method is to be effective. Finally, laboratory findings showing high toxicity to marine life are assumed by potential users to be also valid for the open seas.

Combination of Mechanical and Chemical Methods

The *advantages* of using a combination of methods are that decision makers have more flexibility in choosing their responses and that it is possible, simultaneously, to use one method in one area and another method in a different area.

The main *disadvantages* are that operators need to be familiar with both types of method and that decision makers require a thorough understanding of which means are more useful under which conditions.

*Summarized from the Workshop discussions by David W. Fischer, International Institute for Applied Systems Analysis.

Selective Responses

The *advantages* of a policy of selective responses are as follows. The policy recognizes that it is not possible to treat the entire spill, no matter which means are employed. The sea itself plays the major role in dissolving the bulk of the spilled oil; at the same time, human efforts can be concentrated on the areas of greatest potential damage.

The *disadvantages* of such a policy include the continuing controversy over the long-term effects of dissolved oil in the open sea. Also, detailed a priori knowledge of spawning and migration areas, as well as other ecologically sensitive locations, is needed before the policy of selective responses can be successfully applied.

Doing Nothing

The *advantages* of this "strategy" may be listed as follows. In time, the sea will dissolve spilled oil without any outside intervention. The greatest levels of toxicity generally occur before a proper response can be mounted, and the effects of oil on marine life in the open sea often appear to be minimal. Finally, this approach is obviously the least expensive, at any rate in the short term.

The main *disadvantages* of doing nothing are that the public will almost always demand *some* response, regardless of the effectiveness of the method used, and that there will be the possibility of eventual toxic effects, depending on the type of spill and on when and where it occurs.

9.7 THE ECOLOGICAL EFFECTS OF USING DISPERSANTS: EXPERIENCE IN THE UNITED KINGDOM*

Introduction

During the cleanup operation that followed the *Torrey Canyon* disaster in 1967, dispersants were misused on a massive scale. The ecological damage that resulted was a cause of concern, and the areas of coast affected were extensive. The materials used were originally formulated as industrial degreasers without regard for their toxicity. Their application by untrained personnel (fire services, soldiers, and local-authority employees) and the large volumes used created more biological damage than that from the oil itself. The few people with knowledge of the effects of the dispersant used were not consulted, and attempts to communicate advice on safe use were blocked by a harassed administration subjected to "advice" from numerous sources and considerable public pressure.

The materials used (mainly BP 1002) were highly toxic to marine life (LD_{50} 3.3–10 ppm *Crangon crangon*) and were typically poured onto beaches, into streams discharging into the sea and over cliff tops, and into oil slicks around the Devon coast. Biologists recorded damage to rocky shores, sandy beaches, muddy inlets, and salt marshes [1–3]. By the time of the Santa Barbara disaster in 1969, the early dispersants had gained

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a very bad reputation and their use was discouraged in some countries and banned in others, although a great many continued with their use and development.

These same materials had been used carefully for some years in places such as the oil port of Milford Haven, where their effects had been studied by the Dale Ford Field Centre [4], Orielton Field Centre, The Field Studies Council's Oil Pollution Research Unit [5], and the University College, Swansea [6, 7]. At Milford Haven no long-term damage had been recorded except in one or two limited areas such as salt marshes [5]. Here the nature of BP 1002 was understood and its use carefully controlled with basically good techniques, including post-spraying agitation [8].

Even in Devon after the *Torrey Canyon* accident, few offshore and sublittoral effects were observed and no adverse effects on fish catches were recorded. It is the widespread view among European Fisheries Authorities that oil-spill removers do not present a hazard to commercial fisheries [9–11]. No sublittoral damage attributable to dispersant use was demonstrated and the damaged shores had substantially recovered ecologically within three years with virtually total recovery within five years. There was some evidence of loss of fish eggs from the immediate area and young pilchards were said to be scarce in the area in which dispersants were used at sea [1]. No evidence of depleted fish stocks was found by assessments of fish landings in the ensuing season [9].

During this period the ecological effects of dispersant use were studied by the Field Studies Council's Oil Pollution Research Unit at Orielton [12, 13], the Marine Biological Association at Plymouth [1], and other laboratories, including those of the UK Ministry of Agriculture and Fisheries [10, 14].

Development of Improved Low-Toxicity Dispersants

After the *Torrey Canyon* investigations, the oil industry conducted research that lead to the development of new low-toxicity dispersants, which were introduced commercially in 1969. It was discovered that the toxic component of the original materials was largely in the solvent, particularly the aromatic component. It was also specified that new materials should be biodegradable to ensure that they were nonpersistent. The second-generation dispersants that resulted were low-toxicity materials such as BP 1100, almost 1,000 times less toxic than the BP 1002 which they replaced (48-hour $LD_{50} > 10{,}000$ ppm *Crangon crangon*); these materials were toxicity-tested by the UK Fisheries Laboratory at Burnham upon Crouch and by independent laboratories [15, 16]. Large numbers of species were used. Results obtained by Crapp et al. [17] and Crapp [18] at the Oil Pollution Research Unit at Orielton have shown the huge decrease in toxic properties of the new materials.

Shortly after the introduction of BP 1100, even better materials based on a kerosene solvent with less than 3 percent aromatic content were commercially developed, e.g., BP 1100X, and Table 9.7.1 shows how this dispersant ranks against nine other materials, including BP 1002 and BP 1100, in tests conducted at the UK Fisheries Laboratory [14]. It can be seen that BP 1100X is better than BP 1100 by one order of magnitude.

BP 1100X was put on the UK government list of approved dispersants and rapidly became the most widely used dispersant in the UK and large parts of Europe. It was adopted as the standard material by the port of Milford Haven, which is probably the best biologically monitored oil port in the world.

TABLE 9.7.1 A comparison of rank orders of ten dispersants for *Crangon* and *Cardium*[a].

Dispersant	48-hour LC_{50} (ppm)	*Crangon* rank	*Cardium* rank
Slickgone 2	3.3–10	1	3
BP 1002	3.3–10	2	5
Gamlen OSR	3.3–10	3	1
Cleanasol	33–100	4	2
Atlas 1901	100–330	5	4
Dermol	100–300	6	6
Polycomplex A	100–330	7	7
BP 1100	1,000–3,300	8	8
Corexit 7664	3,300–10,000	9	9
BP 1100X	(> 10,000)	10	10
		$r = 0.843$	

[a]Published by UK Ministry of Agriculture, Fisheries and Food.

Other companies soon produced low-toxicity materials of their own and many of these were put on the accepted list. In the toxicity tests used to gain approval, BP 1100X became a standard reference material (> 10,000 ppm 48-hour LD_{50} for *Crangon crangon* was the pass standard expected).

BP 1100X has now been used in almost thirty countries, from which no adverse effects on fisheries have been reported in field use. The countries include the UK, Canada, Denmark, France, Norway, Hong Kong, Indonesia, New Zealand, and Sweden. Materials developed by other companies have also been widely used in many countries; the concentrations in water reached during field use fall well below those shown to be toxic in laboratory toxicity tests (see below).

All these second-generation dispersants were designed for neat application; however, recently new concentrate dispersants have been developed, which are used after dilution with sea water. These materials offer logistic advantages; since they are concentrates, smaller quantities of material need be transported and stored. For any given volume, longer spraying times and better use of boat time at sea can be achieved. The toxicity of concentrate dispersants at the dilution recommended for use is similar to that of approved second-generation formulations (> 10,000 ppm). They have been toxicity-tested at the required dilution by the Burnham upon Crouch laboratory and have been approved for use by the UK government. Other companies have also developed concentrated materials with similar toxicity characteristics. Even more recently there have been interesting developments of dispersant application by aircraft. Initial tests are promising, but the materials have not yet been fully evaluated under field conditions. In the past, aerial application of conventional dispersants has not generally been effective, because of the lack of mixing after spraying and the difficulty of ensuring that the dispersant reaches the oil, particularly in windy conditions. If suitable aerial spraying techniques can be developed that utilize the materials efficiently and use materials that require minimal agitation, then there would be distinct logistical advantages.

Toxicity Testing and Bioassay

At a recent Institute of Petroleum Workshop on the toxicity testing of oils and dispersants [19] the dangers of making ecological predictions from laboratory toxicity tests were emphasized by the authors of several papers [20]. It was agreed that laboratory tests are useful for ranking dispersants in order of toxicity and can provide a guide for assessing improvements in the formulations. Laboratory results, however, are on limited numbers of species and take no account of community interactions and interspecific competition effects. They are also usually conducted at concentrations far higher and for longer periods than are obtained under field usage. Field evaluation is essential before a final judgment is made.

The toxicity tests used by the British Ministry of Agriculture, Fisheries and Food have been based on the shrimp *Crangon crangon* using various concentrations of dispersant in sea water for 48 hours. The concentration of 10,000 ppm has become the standard expected for attaining approval by government; however, 10,000 ppm is seldom if ever reached under field conditions at sea and holding this concentration for 48 hours is clearly virtually impossible. The tests used can therefore be regarded as extremely stringent.

When the toxicity response curves of several dispersants tested under the same conditions are compared, it is apparent that their relative toxicities are not constant with time; it follows that rank orders established at different times differ significantly. The standard procedure adopted by the Ministry of Agriculture and Fisheries [14] is to compare median lethal concentrations of dispersants at 48 hours (48-hour LC_{50}) and the "median lethal threshold" concentrations; the 48-hour LC_{50} is retained to allow comparisons with earlier determinations made in the laboratory. After 48 hours little change occurs in the rank order of most dispersants [21]. Wilson [14] has shown that the influence of abiotic and biotic variables is exerted on the lower portions of the toxicity response curve, with the threshold varying only slightly.

It is implicit that any one standard technique should produce closely similar ranking orders irrespective of the test species. Wilson et al. [21] have shown that the toxicity for ten dispersants given by Portmann and Connor [22] can be rearranged to produce a rank order with respect to their standard test species, the brown shrimp *Crangon crangon* (see Tables 9.7.1 and 9.7.2). This order can be compared with those given by other species using the rank coefficient r, where $r = 1 - 6d^2/n(n^2 - 1)$, in which n = number of ranks, and d = difference between any two ranks (see Table 9.7.2).

If the rank orders of *Crangon* and *Cardium* for dispersants which cover this wide range of toxicities are compared, there is good agreement (see Table 9.7.1). This table also shows quite clearly the improvement in dispersant technology, the second-generation materials such as BP 1100X and Corexit 7664 having an LC_{50} value on the order of 10,000 ppm, while the earlier materials had an LC_{50} value of 3.3–10 ppm.

If the LC_{50} values of these materials obtained in laboratory tests are compared to the concentrations that are obtained under field conditions, as given in Tables 9.7.3 and 9.7.4, it can be seen that serious concentrations of modern dispersants are not found when oil spills are treated at sea, although lethal concentrations of the first generation of dispersants would have been found (e.g., 4.8 ppm of BP 1002, whose LC_{50} = 3.3 ppm).

The rank orders of all species of crustacea show close agreement but significant differences exist between these and the clam *Cardium edule*. However, the toxicities of these ten dispersants ranged over only one order of magnitude.

TABLE 9.7.2 A comparison of rank orders of ten dispersants to four species of marine animal [21].

Dispersant	48-hour LC_{50} (ppm)	*Crangon*	*Pandalus*	*Carcinus*	*Cardium*
Slickgone 2	(3.5)	1	1	4	4
BP 1002	(5.8)	2	3	1	8
Slickgone 1	(6.6)	3	2	6	5
Gamlen OSR	(8.8)	4	7	3	2
Essolvene	(9.6)	5	5	2	7
Polyclens	(15.7)	6	4	5	9
Cleanasol	(44.0)	7	8	7	3
Slix	(119.5)	8	6	8	1
Atlas 1909	(120.0)	9	9	9	6
Dermol	(156.0)	10	10	10	10
r		–	0.879	0.818	0.152

TABLE 9.7.3 Concentrations (ppm) of crude oil and dispersant with time following chemical dispersant treatment in the upper meter assuming 1:10 dispersant oil ratios [23].

	Run 1		Run 2		Run 3	
Time after spill (minutes)	Oil (ppm)	Dispersant (ppm)	Oil (ppm)	Dispersant (ppm)	Oil (ppm)	Dispersant (ppm)
0	34.4	3.4	24.2	2.4	0.85	0.08
1	–	–	15.8	1.6	–	–
2	47.8	4.8	–	–	8.7	0.9
2.5	–	–	12.2	1.2	–	–
5	–	–	9.4	0.94	–	–
7	17.8	1.8	–	–	3.5	0.35
10	–	–	5.2	0.5	–	–
15	–	–	–	–	1.7	0.12
18	1.9	0.2	–	–	–	–
25	–	–	4.2	0.4	–	–
40	0.8	0.1	–	–	1.35	0.13
50	–	–	1.9	0.2	–	–
80	–	–	–	–	1.5	0.15
100	2.2	0.2	0.8	0.1	–	–

TABLE 9.7.4 Concentrations of nonionic surfactants in water samples collected in oil plume (following the Chevron Main Pass oil spill in 1970 [24]).

Sample no.	Concentration (ppm)	Sample no.	Concentration (ppm)
1 S	1.0	37 S	0.9
2 S	0.2	37 M	0.2
4 B	0.2	38 M	0.2
5 M	0.2	38 M	0.2
5 B	0.2	39 M	0.2
7 S (3 mi WS)	0.2	49 S	0.6

Toxicity Testing for Ecological Predictions

Cowell [20], in a critical examination of present practice, has reviewed various toxicity testing procedures and their problems. Toxicity tests fall into two main categories: those that produce comparative rankings of toxic materials, and those that make ecological predictions. The two types are complementary and neither can fulfill both requirements. Comparative rankings are of limited value, but are necessary to governments, oil companies, and manufacturers to assess improvements in formulation technology or the relative risks of one material compared to another. Since field conditions are so different from those in laboratories (owing to dilution factors, weathering effects, dispersion, and interspecific competition), quite separate field experiments are necessary to assess and predict ecological effects.

No report seems to exist in the literature of offshore use of dispersants that claims significant ecological impacts result from using these materials. Even the highly toxic dispersants used at the time of the *Torrey Canyon* accident do not seem to have affected fisheries.

There are many approaches to laboratory toxicity testing [19]; each research worker may have his own ideas and each laboratory its own preferred method. There are particular problems with oil and oil-dispersant mixtures, and continuous-flow methods are particularly difficult. The techniques adopted by the UK government [14] and by the Canadian government [25] seem to be reasonably satisfactory for offshore dispersant use.

It is a requirement in the USA to test the toxicity of both the dispersant and 1:10 mixtures of dispersant and No. 2 fuel oil. Several materials are currently being examined by the Environmental Protection Agency (EPA) for possible use in waters off the USA.

Other laboratories have worked on dispersant toxicities, including mixtures of dispersant and crude oil. Some workers have produced data showing that such mixtures can be more toxic than either crude oil or the dispersant alone [16]. There is no simple relationship among the toxicities of mixtures, presumably owing to laboratory difficulties in maintaining constant droplet sizes throughout the period of the experiment. There can be little doubt that droplet size is important in the biological effects of hydrocarbon materials; however, almost no work has been done and few laboratories seem to have appreciated the difficulties. Van Gelder-Ottway [16] produced curious results showing that mortalities to two species of shore snail were lower in neat dispersant than when the dispersant was diluted; yet mortalities rose steeply as dilution increased, but then declined with further dilution.

Swedmark [15], working on cod and various mollusc species, had similar results from continuous-flow toxicity tests using 1:1 dispersant oil concentrations for 48 hours followed by 48-hour recovery periods. It is significant that 96-hour LC_{50} values for cod in mixtures quoted for one dispersant were 940 ppm for the dispersant, > 1,000 ppm for Oman crude, and 120 ppm for 1:1 mixtures of dispersant and Oman crude. Similar results were quoted for clams.

The results are vital in oil-spill cleanup procedures, since it is important to ensure that toxic concentrations are not allowed to develop, for example, in shallow waters, freshwater ponds, and areas without adequate dilution potential.

The results obtained in laboratories must, however, be put into perspective. In marine situations at normal application rates, lethal concentrations of dispersant or oil, or mixtures of both, are not found in the water column, and even initial concentrations are not maintained for more than a minute or two at most (usually only for seconds). A situation in which these initial concentrations are maintained for 48 to 96 hours cannot be envisaged outside a laboratory.

It is important to realize the significance of dilution on toxicity. Common salt (sodium chloride) is essential to most marine animals at concentrations of around 30–34%, yet doubling this concentration to 60% kills or seriously affects most marine species. This is obviously not an argument for desalinating the sea! As well as concentration, persistence is an extremely important factor in toxicity determination.

Use of Dispersants in Cleaning the Intertidal Zone

Despite these observations [2, 26, 27], research at Orielton and by the Marine Biological Association [1] has shown that critical concentrations can be reached on beaches that are cleaned with dispersant and that, on most rocky shores in northern Europe, the limpet *Patella vulgata* is the most susceptible indicator of critical concentration. Since the limpet is the dominant herbivore and therefore controls the basic ecological energetics of European rocky-shore ecology, the Burnham on Crouch Laboratory is currently revising its test procedures. Two new approval lists will be published, one for dispersants that can be used offshore and a second for materials that can be used to clean beaches. In both tests the materials will be tested in oil/dispersant mixtures and it will be required that the dispersant/oil mixture should not be significantly more toxic than the oil alone. For the offshore list, the oil/dispersant mixture will be conducted in agitated circular tanks on the shrimp *Crangon crangon*, while for beach-cleaning dispersants, the test used will be on the limpet *Patella vulgata* using the "drop off" test developed at the Oil Pollution Research Unit at Orielton [28]. In addition to its use in toxicity ranking of dispersants, this test has proved extremely sensitive, picking up not only seasonal differences in susceptibility, but also circadian-rhythm variation within the animal, which gives greater susceptibility at night than in the daytime, and shows that in some situations beach-cleaning at night is more ecologically damaging than during the day. Crapp [18] has clearly demonstrated that there are marked seasonal differences in toxicity response to dispersants in different species, so that some animals may be more susceptible to chemical beach-cleaning in a particular season than others in the same community.

The criteria that will be finally used to allow a dispersant to be included in the UK list for beach-cleaning have not yet been announced, but it is understood that most second-generation materials, BP 1100X and similar formulations, will be included, and that the list of licensed materials for offshore use is not likely to be significantly changed.

Ecological Effects of Shore Cleaning

Despite the improvement in formulations and increased government stringency on licensing materials, it is interesting to note that dispersants have been used extensively in Milford Haven for about 15 years and that, for the first 6 or 7 of these years, the toxic BP 1002 was used. Extensive ecological monitoring has demonstrated little permanent ecological damage, except to salt-marsh areas dominated by vascular plants. The overall ecology of Milford Haven is substantially unaffected by the operations of Britain's largest oil port. In addition, a herring spawning ground close to a Gulf Oil terminal has been studied by Nelson-Smith [29] and no adverse effects on herring spawning or migration have been detected. An important clam fishery (*Cardium edule*) at Angle Bay, Milford Haven, South Wales, close to two oil jetties, continues to produce some 200–500 tons of edible clams annually (North-West Wales Sea Fisheries). These are untainted, and in a recent screening for possible neoplasias conducted by Alderman [30] of the Government Fish Pathology Laboratory at Weymouth, Milford clams were given a clean bill of health. No neoplasias were found.

Practical Applications

The UK has now had many years of experience in dispersant use and has developed methods of application that are considered to be both effective and relatively safe for fisheries and marine life. It is generally agreed that, to be effective and to attain maximum efficiency and therefore to use the lowest possible volumes of dispersant, application of both conventional and new concentrate materials should be followed by agitation to ensure adequate mixing of dispersant, oil, and water. The spraying pumps and booms and simple breaker-board equipment developed by the UK Department of Industry, Warren Spring Laboratory, has proved ideal for the purpose and is now marketed in sizes to suit both small and large spraying vessels. In addition, they can be fitted to ships very rapidly. Using this equipment, application rates of one part of dispersant to ten parts of oil are aimed at. While this is easily achieved in extensive areas of oil slick, efficient use in practice falls off when slick and windrows (separated "fingers" of the slick) are being chased by dispersant-spraying vessels.

Where possible, oil should be treated while it is still at sea and while it is fresh, and all efforts should be directed toward preventing oil reaching intertidal areas and hence the coast. When oil is treated at sea, rapid dilution to concentrations below those toxic to marine life occurs and dispersant use is most effective.

If oil does reach the intertidal zone, then most ecologists agree that the safest treatment is to leave it alone for natural weathering and self-cleaning to occur. If amenity and/or recreational interests dictate that cleaning must be done, then this can be achieved with minimal ecological damage by applying the dispersant just in front of a rising tide followed by copious amounts of seawater from hoses to ensure good dispersion and dilution [31]. It is certain that beach-cleaning with modern low-toxicity dispersants is biologically less harmful than the bulldozing, pressure hosing, or steam-jet treatments that are practiced in some areas.

No one method of oil-spill cleanup provides a universally acceptable ecological panacea. No two oil spills are alike, owing to differences in the oil spilled, the local geography, the season of the year and many other factors. Ideally, it is generally agreed that the best solution is first to contain the spilled oil and subsequently to pick it up. Various devices have been developed aimed at achieving this end and some of these are now marketed. Even with the best equipment available, however, if offshore weather conditions are bad, a point can be reached where the deployment of such heavy gear becomes impossible because of dangers to life and limb. At this point dispersant spraying can usually be continued safely, since the equipment is fitted and the ships loaded in the calm of ports or in the lee of large vessels. When it is too rough for even dispersant application, natural dispersion takes place at an accelerated rate.

Dispersants have been used in many countries without adverse effects, under conditions as varied as those in arctic Norway (following the *British Mallard* accident) and Corrunna, Spain (after the *Urquiola* grounding). The oil-spill literature reviewed by Ottway [11] and Van Gelder-Ottway [32] revealed remarkably few cases of ecological damage. There are many instances of successful dispersant use; only a few have yielded reports of significant fishery damage apart from taint or depressed markets.

There are, of course, recent examples of dispersant misuse. Unfortunately, some of the older materials are still stocked; however, the most frequent cause of dispersant misuse is incorrect application techniques. Many examples of this could be cited, but a particular fault is underdilution of dispersants, resulting in the application of larger quantities of active material than are necessary to achieve efficient dispersion, and consequent increases of this material in water-column concentrations.

Ecological Limitations of Dispersant Use

It must be said that dispersants do have biological limitations. Highly viscous fuel oils, waxy oils, and some emulsions are often difficult to treat physically with dispersants unless large quantities of dispersant are applied, these quantities frequently exceeding toxic concentrations, even if only temporarily. Biologically, oil can be treated safely and effectively offshore with damage only to limited amounts of plankton and greatly to the benefit of seabirds; close inshore, however, as a precaution fish-spawning grounds are best avoided in the breeding season; similarly, spraying is best avoided over shellfish beds, etc., to avoid risks of oil taint.

Most marine organisms are resistant to dispersant, particularly to exposure of short duration; this is particularly true of marine algae [31]. However, it must be emphasized that vascular land plants are very susceptible indeed, owing to their lipophyllic surfaces, stomata, and internal conduction systems [2, 33–35]. For this reason, salt-marsh areas including mangrove foliage should never be cleaned with dispersants. Penetration into vascular plants occurs in seconds and no amount of washing with hoses can undo the damage. Toxicity, however, is related to concentration [27] and tidal water containing small amounts of dispersant from offshore spraying does not cause damage to salt-marsh vegetation. Oil close offshore can therefore be safely sprayed to prevent it coming ashore [27, 36]. Under the UK Dumping at Sea Act 1974, licenses are required for the use of dispersants. There are conditions attached to these licenses which effectively control the misuse of approved materials. These conditions prevent dispersant application to ecologically sensitive areas identified by the Fisheries Authorities and the Nature Conservancy Council.

The use of dispersants is not recommended in freshwater rivers or in lakes, unless the lakes are extremely large. Little is known about the effects on freshwater organisms and more research is required. In general, provided the materials are correctly used according to the recommendations of the manufacturers and by trained personnel, dispersants have proved to be a safe and effective method of treating oil spillage at sea. Dispersants can, if used carefully, be used for cleaning oiled rocky beaches and sandy shores [31].

Biological Consequences of Emulsifier Cleaning

Crapp [26] concluded after three years of work that: "When emulsifiers (dispersants) are used sparingly and washed away with large quantities of water, even highly susceptible limpet populations are not severely depleted. Other species may be affected, but the grazing population remains sufficiently numerous to prevent an invasion by brown and green algae."

Crapp also concluded that, with second-generation dispersants, shore-cleaning should be possible without causing extensive biological changes.

Conclusion

Modern dispersants can be used offshore without risk of severe biological effects other than to small areas of plankton in the immediate vicinity of the area treated.

Although second-generation dispersants are much less toxic, they are not recommended for unrestricted use in shore-cleaning. They can be used for rocky shores and sandy beaches without causing major ecological disturbances. The critical factor is the way cleaning is carried out. Several biological factors need to be taken into account: the nature of the oil, the nature of the shore, and the time of the year.

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10 OVERVIEWS

A.J. Fairclough and D.W. Fischer

10.1 NORTH SEA OIL HAZARDS: THE ENVIRONMENT/DEVELOPMENT INTERFACE AND IMPLICATIONS FOR MANAGEMENT*

It is the job of management – of the decision maker – to decide. He may decide well or badly, boldly or cautiously, decisively or tentatively; but sooner or later, decide he must. And usually it is sooner rather than later; and on the basis of information that is far less comprehensive and well integrated than he would wish, and which may well be unreliable.

I shall present – as a decision-maker who has been involved to some extent – some considerations that seem relevant in relation to the process of decision-making in regard to North Sea oil. The quality and quantity of information available on at least the major parameters is important if good support is to be given in a complex developing situation like that pertaining to North Sea oil. Such a situation needs a steady flow of decisions – and it is the decision-maker's function to take them at the right time and in the light of the best information available.

To say this is not, of course, to argue that the decision maker can afford, as is said in the UK, "to fly by the seat of his pants." Of course he cannot; he needs tools, guidance, information in a wide range of fields, and their systematic analysis and integration into a set of aids. But however adequately or inadequately this may be done, when the moment is ripe, he must make up his mind, because he knows that a well-researched decision taken too late may be far worse than one taken at the right time but based on less adequate information.

In relation to most situations, there is no uniquely right set of decisions. In almost all subsystems of the total complex North Sea oil situation, decisions have had to be taken on the basis of less than adequate information. In many of them there is room for perfectly legitimate subjective differences of judgment on the basis of similar facts. And social and political factors also enter in, so that different factors have to be given different weights in different situations, even though the information base is the same.

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Risk Assessment

In relation to North Sea oil development, for very many of the elements on both sides of the environment/development interface, the situation was novel in many respects; hence, certainties were few. On the development side, in relation, for example, to design, construction, operating conditions, corrosion, durability, and so forth, there was little previous experience to go on. On the environment side, rather more was known from other previous large projects in relation to the social, housing, and land-use impacts of large-scale construction and facilities in sparsely populated areas; but the hazards likely to arise from pollution of the open sea, coastal waters, ports and estuaries, important conservation areas, amenity beaches, and so forth, as a result of accident, blowout, or regular discharges, were largely unknown. On both sides of the interface, the suddenness with which events developed increased the difficulties.

As stated in an earlier paper on risk assessment [1], central government is continually faced with the need to assess risks in a variety of fields, using a variety of methods to weigh the very uneven results one against the other, and to form a judgment as a basis for decision-making which, recognizing that zero risk is unattainable, endeavors to find the optimum balance. That balance will essentially be one involving an analysis of the costs, risks, and benefits of both adopting a particular course of action and of not adopting it.

In the earlier paper it was noted that risks can be viewed from several points of view and this is worth repeating here and bearing in mind in relation to the North Sea oil situation. Obviously, one can break down the analysis of risk in a very detailed way if desired, and there are numerous different approaches to risk assessment (as is clear from a recent SCOPE report [2] and a booklet recently published by the Council for Science and Society [3], to mention only two items from the rapidly growing literature in this field). But I think that at the very least it is important to pay attention to: the probability of an event occurring; the nature of the risk (especially whether the consequences are reversible or irreversible); what is at risk; the source of the risk; and related psychological attitudes.

Turning more specifically to North Sea oil, the assessment of the relevant risks has been an integral part of the UK government's approach to all aspects of the matter, both environmental and developmental. On the developmental side this is scarcely surprising, since throughout all phases of North Sea oil development, human lives are directly dependent upon the adequacy of design and engineering of which the assessment of the risks of failure is an essential part. On the environmental side too, risk assessment, although still a very underdeveloped science, has been present from the beginning. On March 18, 1967 the *Torrey Canyon* ran aground near Lands End and during the next ten days or so released about 100,000 tons of oil into the sea. The White Paper [4] published in April 1967 on the disaster made plain that weighing the risks of various alternative courses of action had played a large part in deciding what action to take; and in the final paragraph of the report, the government of the day announced that action through IMCO (the International Maritime Consultative Organization) was necessary to safeguard "coastlines and marine life against the increasing risks of large-scale accidents involving pollution."

In the followup action, risk and its assessment was again to the fore. The Committee of Scientists [5] that reported on the *Torrey Canyon* disaster examined the risks of various adverse effects resulting from oil pollution and the advantages and disadvantages of the various alternative means of dealing with it that were then available. The report on coastal pollution by the Parliamentary Select Committee on Science and Technology [6], which followed in July 1968 and reviewed the whole history of marine oil pollution, including the *Torrey Canyon* incident, devoted the first two chapters of its report to the risks of oil pollution and to ways and means of reducing the risks. The Committee also delivered a ringing declaration of belief which is worth repeating. "All coastal pollution is a disgrace, bad economics and harmful to the environment. It endangers man's own health and spoils his enjoyment of the beaches he so wantonly befouls. To use the oceans as though they were the waste pipe of the world, leading to some bottomless sump-pit, ever capable of absorbing more oil or other noxious substances, is an unethical abuse of the natural environment which man shares with the flora and fauna."

I believe that these sentiments have considerably influenced thinking and developments in the UK since, and it would not be out of place to say why. The Select Committee obviously paid a good deal of attention to the views of Sir Solly (now Lord) Zuckerman, who had been Chairman of the Committee of Scientists, and who gave evidence to the Select Committee. The Committee of Scientists had concluded that: "The *Torrey Canyon* incident revealed a painful ignorance about a number of matters which should now be urgently inquired into if oil is to be more rapidly, safely and efficiently disposed of in any future incident." The Select Committee clearly felt the same; and it went on to make a number of far-reaching recommendations touching on the machinery of government for dealing with marine oil pollution, future emergency situations, and international coordination and cooperation. Although the government of the day, in their observations [7] on the Select Committee's report, did not accept their organizational views, it seems fairly clear that they played an important part in the view that was developing rapidly at that time that clearer and more effective arrangements were needed for the protection of the environment at large. Be that as it may, the fact is that in 1969 responsibility for "coordinating government action on the control of environmental pollution" was given to a single Secretary of State; and, by the following year, the Department of the Environment (DOE) had been established [8], with the Central Unit on Environmental Pollution (CUEP) as an integral part of it and with the standing Royal Commission on Environmental Pollution established "to advise on matters, both national and international, concerning the pollution of the environment; on the adequacy of research in this field; and the future possibilities of danger to the environment."

In the White Paper on the protection of the environment [9], which preceded the establishment of DOE by some six months, there had been reference to the *Torrey Canyon* accident, to action under way through IMCO and to work in progress to reduce the risks that accidents at sea may cause pollution. In addition, the White Paper referred to an interlocking system of local authority plans and provisions for beach-cleaning should oil come ashore, developed since the *Torrey Canyon* disaster, and it went on to anticipate the sort of control that the government intended to exercise should "oil in commercially exploitable quantity" be found around the coasts of the UK. The government would "control and supervise the conditions under which it is produced and distributed" with, as one important object, "to guard against the possibility of oil leaks . . .". The government would also continue "in consultation with the oil industry, to regulate the conditions of oil exploration and production so as to prevent accidents . . .".

The general approach thus defined has remained the approach of the UK ever since, with numerous parts of the government machine involved in the total process. In organizational terms, therefore, the scene was set for the discovery of North Sea oil and for environmental input into the controls exercised over its development. The scene was set, too, for the close watch that has been kept by the Royal Commission on marine pollution and the environmental impacts of North Sea oil development (several of its reports [10, 11] discussed the problems arising) and for the involvement of the Central Unit on Environmental Pollution, with its responsibilities – matching in breadth those of the Secretary of State – "to coordinate the government's action to combat pollution."

The United Kingdom Approach to Decision-Making

First, may I stress that very considerable importance is attached in the UK to the doctrine of collective responsibility. This means that each minister speaks for the government as a whole in putting forward the policies of his own department. Implicit in this is the aim of consistency across the whole range of government policies, rather than confrontation in support of particular departmental interests. This in turn means that, both at ministerial and at official level, a very high degree of interdepartmental consultation, coordination, and cooperation is essential. Of course the primary responsibilities of each department or ministry are different. But, flowing ultimately from the doctrine of collective responsibility, it is an essential feature that the Petroleum Production Division (PPD) must *also* be concerned about environmental protection, and CUEP must *also* be concerned about development, given that these interests both have their part to play in national policy overall.

As far as concerns the onshore impact of North Sea oil development, it is necessary to look at land-use planning arrangements in the UK, which have operated, on the whole successfully, for over 30 years. A very important part of the whole system is the wide range of measures concerned with various aspects of positive planning that are involved and – this should be stressed – it is not only concerned with the control of development. The positive planning arrangements, all fully debated in and established by Acts of Parliament, cover such matters as national parks and nature reserves, industrial location, regional policy, heritage coasts, the control of office development, green belts around urban areas, as well as the positive requirement laid upon local authorities in the UK to publish and have publicly examined their policies and plans for the use of land in their areas.

Mention should also be made of the statutory establishment of the Nature Conservancy Council in 1973 [12] and the Countryside Commission in 1967 and 1968 [13, 14], which formally institutionalized concern for these aspects of the environment. These bodies are funded, on a growing scale, by central government; they act entirely independently of central government under their own controlling bodies, they play an active part in the land-use planning process, and they give advice to – and on occasions argue with – central government on environmental issues that fall within their terms of reference. They have certainly played a part in the development of North Sea oil.

Indeed, it can well be argued that the whole system – positive planning and the exercise of control over development, which has dealt perfectly satisfactorily over the years with many major developments – would have been fully adequate to deal also with North Sea oil, had it not been for the suddenness with which and the scale on which new developments became necessary in areas whose local authorities were unused to, and lacked the manpower for dealing with, massive proposals of this character. In any event, a great deal of what was necessary to deal satisfactorily with these new developments was in reality handled through the planning system (assisted, at the peak, by 15 consultant groups engaged by government, local authorities, and oil companies, and supplemented by only a very few special measures, some of which are referred to later). It needs also to be remembered that the essential feature of the planning system of the UK is that, in arriving at decisions about the use of land, all relevant considerations must be taken into account. This means, inter alia, that all environmental impacts are considered and weighed in the balance with other factors. Thus any onshore hazards likely to result from North Sea oil-related developments, whether in particularly sensitive areas or in more normal areas, are considered at the time that planning decisions are taken. In the remainder of this section the focus of attention will be offshore hazards; this is not because onshore risks are considered unimportant, but simply because the machinery for dealing with offshore hazards was much less well developed when North Sea oil development began, whereas the planning system, by and large, satisfactorily limited and controlled the onshore risks.

To summarize, in order to understand fully how the UK reached its present balance between development and environmental protection in relation to North Sea oil, it is necessary both to look further back into the history of the matter and to recognize that present arrangements had their genesis in the mounting surge of environmental awareness during the 1960s and were powerfully influenced by the *Torrey Canyon* disaster; and also to view them not in isolation, but within the framework of the overall arrangements established in the UK for protecting the environment. Those who wish to pursue these aspects of the matter further should refer to a relevant article in the literature [15].

So far as the environmental side of the interface is concerned, special importance is attached to the establishment of the Royal Commission on Environmental Pollution, which was, from the outset, conceived as providing "the main source of independent advice to the government." It is interesting to note that the commission has not to date been unduly concerned about pollution hazards arising from North Sea oil. In its most recent comments on the matter, the Fourth Report [11], the commission recorded that, following discussions "with officials of the Department of Energy and with one of the oil companies" and relevant visits, it had "been reassured by the safeguards that have been made to deal with accidental spills that could occur." The Royal Commission went on to say that it had "concluded that there is no need at present for us to pursue the matter further, but we [the commissioners] are bound to keep an anxious eye on it," and that it welcomed the investigation "being undertaken by the Central Unit on Environmental Pollution within DOE in conjunction with other departments concerned" – the investigation which later appeared as Pollution Paper No. 8 [16] – and said that it would keep in touch with progress (as indeed it has).

North Sea Oil – Current Areas of Concern

Some of the main areas of concern that have affected the perception of the environment/development interface concerning North Sea oil in UK eyes will now be considered in greater detail. The development side of the interface will be discussed first. The UK attaches great economic importance to oil production from its sector of the North Sea. As the government put the matter in a White Paper [17]: "North Sea oil provides a unique opportunity for Britain to improve her economic performance, raise her living standards, move forward to full employment, and develop as a socially just society. It will also put her in a stronger position to discharge her international responsibilities, not least in relation to developing countries." The importance of North Sea oil to the UK is thus seen as very fundamental, right across the economic and social spectrum. The White Paper records the weak balance of payments situation in the UK and the slow productivity growth and long-standing lack of competitiveness of some of the major industries and goes on to say that: "As a result of this long period of decline, our living standards, which were among the highest in Western Europe a quarter of a century ago, are now among the lowest."

North Sea oil, whilst it is seen as presenting a great challenge, is thus also seen as providing the UK with a great opportunity to correct these inadequacies of the past. No view of the UK approach to North Sea oil that neglects these vitally important elements in the overall picture will be adequate.

Related to these important economic and social considerations are questions about the rate at which North Sea oil should be developed. It was decided to go for a rapid rate of development until the point was reached, in 1980, where net self-sufficiency was achieved. This needs to be seen in relation, not only to the social and economic considerations already mentioned, but also to the overall energy policy, on which a Green Paper [18] has recently been published. Energy policy is not yet firm or fixed, but seeks to develop a variety of possibilities and to keep a range of options open for the future. Meanwhile, solutions to the problems arising in connection with nuclear power (the Royal Commissions's Sixth Report [19] and the government's response [20] thereto discuss these) and the longer-term potential of renewable sources of energy are being pursued urgently. Whilst this work is going forward, North Sea oil and the very large coal resources (together with a vigorous program of energy conservation, which was further extended very recently) leave the UK in a relatively fortunate position in energy-supply terms. Clearly, however, as time passes, oil, whether indigenous or imported, will become scarcer and more expensive. At the same time, knowledge of the North Sea reserves is increasing. It can only be in this context that the changing rate of exploitation of North Sea oil and the timing and phasing of the inevitable changeover from its use as a fuel to its use as a feedstock can be determined.

Design, engineering, structural, and safety considerations also inevitably remain areas of prime concern on the development side of the interface. Here all that one can say is that, since operation is often beyond the limits of experience, risks must inevitably be high by comparison with more normal situations, although they seem to be declining as learning proceeds. This much said, however, it is right to add that experience to date is still too short to permit many secure conclusions to be drawn.

Of particular concern from the standpoint of the environment/development interface is technology that is directly relevant to preventing oil pollution – accident and blowout prevention, oil/water separation techniques and equipment, pickup and treatment techniques, and equipment for oil that is spilled. The Ekofisk Bravo and the *Amoco Cadiz* incidents show there is still scope for improvement in both blowout and accident prevention, even obvious things like not assembling equipment upside down and sensible routing arrangements would clearly help. The close bilateral links that the UK is developing with both Norway and France cover many aspects of North Sea oil development and tanker movements and these will certainly help.

On the environment side of the environment/development interface, the most obvious matters of environmental concern were discussed in Pollution Paper No. 8 – questions about the risk and frequency of incidents involving discharges of oil into the sea in the various sectors around the coasts of the UK, the scale and seriousness of the effects of oil discharges, both massive and routine, on marine life and on amenity, and the balance of the debate about the merits and demerits of various ways of dealing with oil that is spilled, ranging from doing nothing through to massive onslaughts with dispersants.

The purpose in mentioning these various areas of concern is to underline the importance and complexity of the issues arising and to reiterate that in relation to most of them there is a profound lack of reliable experience and data. The problems of North Sea oil development are too new and too unusual to make it easy to judge on the basis of the past. Moreover, so far as possible major hazards are concerned, statistics of occurrence are rarely useful, since major incidents are by definition rare and almost certainly arise, in each case, because of a peculiar and unusual concatenation of circumstances likely to be unique to that case.

Even in relation to the subsidiary elements in the overall system, the difficulty of learning from experience is present to a greater or lesser extent in many of them. Pollution Paper No. 8, for example, looked at the risks of oil spills around the UK: whilst it arrived at fairly specific conclusions (i.e., that in 1981 the cleanup organization is likely to be called out three or four times to deal with tanker spills, of which one or two are likely to be greater than 135 tons whilst there could in addition be four or five platform or pipeline spills greater than 135 tons) it revealed on closer examination that to arrive at these conclusions, some fairly sweeping assumptions had to be made, along with some fairly arbitrary decisions designed to relate experience elsewhere to the North Sea situatin. Although this appears to be adverse criticism, it must be recognized that actual statistical information on North Sea experience was not available, and the forecasts made in Pollution Paper No. 8 can only be fairly judged on actual experience.

So the situation can only be summed up as follows: there are no easy answers, and there are very few certainties. What is involved is the exercise of judgment in such a way as to integrate available information into the decision-making process at each stage. The main requirement is to ensure to the greatest possible extent the comprehensiveness and relevance of the information available, on the basis of which balances will be struck and judgments made. In such a complex and uncertain situation as that surrounding North Sea oil development, the judgments that are made can perfectly validly differ. Indeed, given the very wide range of factors involved in decisions at the environment/development interface, it is virtually certain that they will.

There are a couple of elements in the total picture that make it perfectly understandable why UK and Norwegian conclusions should be different. Consider first the economic implications. The crucial economic and social importance of North Sea oil to the UK is the perceived opportunity to arrest long-standing decline and once more become as prosperous as the rest of Western Europe. Is it surprising that the UK should seek to press ahead rapidly with development? By contrast, consider Norway: a small population with a relatively high standard of living already and with a very sensitive and precautionary approach to resource conservation and to any action that could result in harm to living systems. In economic terms Norway has less need to press ahead fast with North Sea oil development; indeed it seems to me – if I may, as a foreigner, presume to comment – that to go relatively slowly is entirely consistent with their attitude to very many other aspects of national life. The result is a perfectly legitimate and understandable difference of approach between the two countries, which must be recognized.

Take another, perhaps less dramatic, example. Fishing interests play an important part in Norwegian life and are politically powerful. The Norwegian authorities are therefore perfectly naturally very sensitive to oil pollution and action to control it; they take the view that the large-scale use of dispersants may risk harming fish resources, especially spawning grounds. By contrast, in the UK there is an enormously strong and widespread interest in and concern about the well-being of birds, and hence a need to remove oil from the sea surface when birds are threatened. That is not to argue that Norwegians are not interested in birds or that the UK has no concern for fish; merely that the priorities differ in the two countries and that the effect of this fact is to make action to protect fish more urgent in Norway and to protect birds more urgent in Britain. Another perfectly legitimate difference of approach.

Finally a related point: although in general both the UK and Norway regard inaction, pickup equipment, and dispersants as all having a part to play in dealing with spilled oil, there is no doubt that Norway is very inclined to rely on pickup equipment and to be very hesitant about using dispersants, whilst the UK is sceptical about the former and much more ready to use the latter to protect the coast, marine life, or concentrations of seabirds. Personally, I think that the Norwegian view is mistaken. The UK certainly sees the advantage of effective pickup equipment and substantial efforts are being devoted to developing better recovery systems. Meanwhile, when leaving spilled oil to disperse and degrade naturally is not acceptable, UK policy [21] is to rely on spraying with dispersants as "the only method of dealing with spills so far proven to be really effective at all times in the seas surrounding the UK." Modern dispersants are much less toxic than those used at the time of the *Torrey Canyon* disaster – the criterion for passing UK tests is that the toxicity of the oil/seawater/dispersant mixture must not exceed that of the oil/seawater mixture on its own. Do not forget that, even at the time of the *Torrey Canyon*, the Parliamentary Select Committee that looked into the whole matter concluded that: "On the open sea there are not really strong biological grounds for eliminating the use of toxic detergents." To rely at the present time entirely on mechanical pickup seems to me to fly in the face of the facts. Nevertheless, having said this, I must add that although I disagree with Norwegian policy, I think that I fully understand the considerations underlying the Norwegian attitude. Here again there is a perfectly comprehensible difference of view, although in this case I think it is one that might gradually be reduced on the basis of experience, developing technology, and scientific facts.

Future Concerns

In a situation as complex as the development of North Sea oil, one is never faced with certainties. A decision-maker will always have to make his mind up – because some decision is necessary – on the basis of inadequate information and in the face of risks that he cannot altogether quantify; but this is not the same thing as saying that the attempt to quantify should not be made or that the analysis of risks should not be attempted. Quite the reverse. It is clear too that discussions on the systems and subsystems involved in the decision-making process also has a useful part to play, although one must always be wary lest analyses based on inadequate information lead to misleading conclusions. Indeed, to turn this last point around, better decisions will only be possible when they are founded on a more comprehensive view of the totality of the system and better integration of the numerous interacting subsystems, that is, when the information and data base have improved. With this in mind, how might matters be improved in the future?

In considering the environment/development interface in relation to North Sea oil, one is, from the environmental point of view, dealing with technology-associated disasters (or impacts). To improve judgment in relation to such impacts, the clear need is to improve the knowledge of the technological limits and risks. In Chapter 7 of Pollution Paper No. 8, the three possible approaches to the problem of assessing the risks of oil spills that were considered are set out. In fact, it was decided to base the calculations on a Massachusetts Institute of Technology study; but the possibility of undertaking component reliability analysis on the lines developed by the United Kingdom Atomic Energy Authority in relation to nuclear installations was considered. It might be, as technology becomes more established (and as experience grows) in relation to North Sea oil, that a critical engineering approach of this kind rather than a merely statistical approach to risks might well have something to be said for it.

A second area in which improved knowledge is clearly needed is the environmental consequences of oil spills in different quantities and circumstances. Better knowledge of how such consequences can be limited, contained, or dealt with is essential and this plainly involves both research (for example on the effects of oil and dispersants on marine ecosystems) and also technological development (for example on the means of restricting massive or chronic discharges and on developing effective booms and pickup equipment). The Committee of Scientists that reported on the *Torrey Canyon* disaster spelled out many of the needs in this area: they said, for example, that research was needed on the effects of natural factors on the movement, dispersal, and destruction of oil at sea; oil sinking, scavenging, and gelling agents; more-effective but less-toxic detergents; detergent spraying and other cleansing equipment; mechanical methods of removing oil both from the sea surface and from beaches; cheap and effective booms to protect harbors and inlets; and the effects of pollution on marine life, seabirds, and coastal vegetation, and on ways of minimizing them.

The Parliamentary Select Committee that reported the following year supported these recommendations, expressed disappointment that more progress had not already been made, and added some further recommendations for research that had been proposed in the USA, which should also be considered. Since that time a good deal of progress has already been made on many of the matters listed above, and substantial programs of research are currently under way, notably on dispersants and pickup systems. Nevertheless, the understanding of the effects of oil on marine ecosystems in particular is still far from adequate, and the DOE is at present making an effort to mount a fuller research program in this area.

A further point for the future that emerges from an analysis of North Sea oil development may be expressed as "trying in new developments and new bonanzas to get things more nearly right from the start." Obviously, unless talking about further major offshore oil developments, one is not thinking about developments or bonanzas that provide exact parallels; nor where experience would be directly relevant. It is worthwhile, however, to examine what precisely did actually happen in relation to North Sea oil. The aim must be to see what, if any, lessons there may be of wider application, implicit in the way things were handled: the sequence of events, the organization of management, the comprehensiveness of consultation, the timeliness of guidelines, and so forth.

I will not attempt to suggest all the lessons of this character that may be learned. So far as the UK is concerned, there are three situations that would repay study. The first, which is probably best studied in the UK itself, is the sequence of events that I described in some detail earlier surrounding the *Torrey Canyon* disaster, when this first major incident involving massive oil pollution of the sea came together with developing concerns in other fields of environmental protection and led rapidly to important organizational and structural changes within government.

The second UK example that may repay study is the question of the effect and value of the coastal planning guidelines published by the Scottish Development Department [22] in 1974. In my judgment, these guidelines were one of the more important of the small number of special steps taken in relation to North Sea oil to augment the normal planning processes, and played a very considerable part in limiting adverse onshore impacts. The guidelines included a map showing preferred development zones and preferred conservation zones around the coast of Scotland. The associated document made plain that the former were areas within which sites for oil- and gas-related development seemed likely to be appropriate and that, whilst not all types of operation would necessarily be acceptable or feasible, developers should look in these areas for suitable sites; and the planning authorities were advised to prepare development plans in anticipation of developers' requirements in these zones. In relation to preferred conservation zones, it was indicated that there would be a general presumption that the areas were of such national scenic, environmental, and ecological importance that major new oil- and gas-related developments within them would be inappropriate; and that any intrusion into such zones would have to be justified by compelling arguments, including the demonstration that no suitable sites existed outside such zones. This was a relatively simple but extremely effective step, which was backed up by a requirement that all major oil- and gas-related developments should be notified to the Secretary of State. The advantage seen in it was that (given that there was a need to site new developments in a way that made the best use of existing labor and infrastructure and minimized the effect of subsequent decline) there would be considerable benefit in grouping developments, preferably in or near existing population centers, so as to avoid a scatter of industrial development affecting many small communities and numerous rural areas, and so as to allow the full use of existing labor pools, housing, and public services, the economic provision of additional services, and the possibility of diversification to cushion subsequent decline. As will be seen from this brief statement of aim, this short and simple document achieved a very considerable degree of comprehensiveness; and it brought together a large number of the subsystems involved in the whole process associated with North Sea oil development.

The third area which I suggest would repay further study and analysis is the whole area of risks arising from technological failure. I have already referred to the possibility of using a critical engineering approach in relation to design. But I am now talking about something rather more broad than that – an analysis of the various sources of risk on the lines undertaken in a paper published by the Scottish Office at the request of the Oil Development Council for Scotland [23] while the study that led to Pollution Paper No. 8 was under way. In a chapter entitled "The Risks of Pollution," seven main types of accident likely to lead to discharges of oil into the sea were analyzed and discussed. Pollution Paper No. 8 took this process further. My own view is that it could be taken further yet and that, by breaking down the overall picture into subsidiary elements and analyzing the risks of failure in each, a better understanding, both of the subsidiary elements themselves and of the total overall risk picture might well be obtained.

The final suggestion about concerns for the future relates precisely to the IIASA's own remit, the systems view. This is not because I think that decision-makers always (or pehaps ever) perform in accordance with the diagrams and charts that analysts produce, but because it seems that it is valuable to endeavor to discover the response sequence, the interdependencies and interactions, the prior and subsequent elements, and so forth, so as better to understand how things might work (even if not how they actually do!). As I see it, the systems approach is at its best when it allows cooperation in a consistent manner using some explicit agreed model; and the aim obviously has to be to make the model as close as possible to reality. Plainly this is very difficult, unless at least the major variables can be quantified; and equally plainly the ideal is never achievable. Personally I doubt whether there is an ideal or whether there is a unique model. But unless one endeavors to spell out how it might be, an ad hoc condition exists and the possibility of benefitting from past experience might be lost.

My own view is that the systems approach can indeed help; but it is also most emphatically my view that it will never answer the decision-maker's problem. Judgment will always be essential. The aim should be to ensure that it is a better informed judgment. This will only come about if a conscious effort is made to secure better information and to learn from experience; and also to correlate information and experiences in relation to the various elements in the overall system. In this event – and that is precisely what IIASA and this workshop have been attempting – then really useful models might be developed, instead of always having to start from lots of new beginnings.

A final point on information: it is all very well talking about analyzing and systems and models, but this is all so much whistling in the wind unless it is all very firmly founded in reality. This means that facts are needed. This in turn means that research is needed to improve the understanding of basic processes, and also that monitoring is essential. Not just monitoring for its own sake -- that is foolish and pointless – but monitoring that is properly related to policy issues and needs, to the requirements of management and decision makers, whether they be developers, environmentalists, regulators, or entrepreneurs. If one can assemble, manipulate, retrieve, and analyze relevant data of this kind, then the systems approach will be founded on firm ground and valuable lessons can be learned for the future, not only in relation to offshore oil development but perhaps about many other important and complex areas of activity where there is a significant environment/development interface.

Conclusion

Management's job is to manage; the decision-maker's job is to decide. At the environment/development interface the essence of the task is to judge the appropriate balance between costs and risks and benefits, of both action and inaction. This seems to me a statement that is perfectly generally true; and just as powerfully so for North Sea oil as for any other example. But the system within which judgments are necessary in relation to North Sea oil is a peculiarly complex one; uncertainties abound and will remain. Whilst the systems approach and models of the interacting sets of subsystems involved may help and may assist management in making better judgments, they will not replace judgment.

The essential role of management, whether the developer or the environmental protector, remains: to decide. At the right time and on the basis of such information as is available on all the multiplicity of relevant factors that go into the decision-making process – but nonetheless to decide.

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10.2 ROUND-TABLE DISCUSSIONS – A SUMMARY*

Pre-Blowout Incidents and Regulation

Blowouts do not begin immediately with no prior warning, and, even when they do occur, there is often time to recognize their imminence and take measures to prevent the blowout or ensure the safety of personnel before abandoning the rig. All drilling operations may be viewed as a series of minor incidents and problems that the crews generally succeed in overcoming: blowouts result from the rare sequences of events that are not successfully controlled. In the immediate pre-blowout period, one event leads very rapidly to the next, so that a number of elements are needed to keep the incidence of blowouts low — responsible operating practice, comprehensive crew training, frequent safety and emergency drills, and good luck. In such a complex situation, no regulator can hope to design a system that will be 100% effective in preventing blowouts, although this must always be the target.

Detailed regulatory practices differ from country to country, but some important elements can be discerned. Canada requires operators to present contingency manuals outlining their response to every incident that could lead to a blowout. In the US, all incidents and accidents that occur during drilling must be reported; the information is then collated and circulated to all operators. Another US regulation requires operators to maintain continuous radio or telephone contact with the central authorities throughout all emergencies, so that any potential blowout can be assessed and, hopefully, prevented before it begins. Furthermore, US regulatory contacts are continued over fairly long periods; the operator and regulator often get to know one another on a first-name basis and are familiar with each other's strengths and weaknesses, thus tending to ensure complementary responses during emergencies. Cases have been reported, in Canada and the US, of drilling supervisors requesting regulators to put pressure on operators to change onsite drilling practices which the supervisors regarded as unsafe.

Over-regulation could be counterproductive but even in the US, after 25 years of progressively tighter regulation, it is felt that this stage has not yet been reached. Any efforts to introduce or extend regulation should of course avoid adding unduly to the amount of paperwork and reporting needed because these can create "noise" in the feedback signals necessary for safe drilling by taking supervisors away from real supervision and thinking about drilling problems. An extreme reaction to regulation is sometimes exhibited by drilling crews from countries with very few or no regulatory procedures; such crews have been known to complain of over-regulation when subjected to even the most streamlined procedures.

One difficult problem for regulators is to decide whether the operators and drilling supervisors are truthfully reporting the real drilling conditions experienced on the platforms. Similarly, even those operators with the best intentions, the best instruction manuals, and the most comprehensive safety policies are sometimes unaware of what is

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really happening on their own platforms, because the operators are onshore and their delegated managers on the platforms send back incomplete or inaccurate information. Difficulties have been experienced in feeding back the benefits of new information or revised operating recommendations into the normal safety procedures of operators and drilling crews. One somewhat alarming conclusion is that it seems to be necessary for a catastrophic situation to actually occur before operators and regulators feel able to communicate frankly and realistically about operational problems.

Post-Blowout Lessons and Research

Experience from blowouts has shown that there is often a complete lack of coordination between the research carried out by regulators, operators, and other experts, even though there is informal liaison between the groups; the introduction of a certain amount of control, if only to prevent fruitless duplication of work, would seem worthy of future efforts. Of course, it is not really possible (or necessarily desirable) to impose a completely coordinated research plan on individual scientists who differ so widely in academic qualifications, motives, and personal interests. However, some steps have been taken. In the US, for example, a scientific coordinator is now appointed after each major oil spill to ensure that scientists from different organizations do not duplicate their efforts and generate a plethora of different interpretations of the same observed data. (The magnitude of the problem was illustrated when the *Argo Merchant* spilled its oil and nearly 400 scientists converged on the area with very similar ideas of what should be studied.) Organizational issues aside, the basic scientific unknown (despite extensive research and documentation in the US) is still the physical fate of the oil in the sea.

As in other areas, scientific advice, and more particularly the publication of this advice, can be a two-edged sword. Scientists themselves generally attach a series of qualifications to any answer given, but these qualifications are often forgotten by the non-scientific audience and educated guesses become transformed into "facts." Similarly, decisions tend to be seen by the public as being based on all possible information whereas they are often in reality only the best possible decisions in the light of very limited information. These types of pressure and the possibilities for misunderstanding can make scientists very reluctant to give opinions on practical short-term problems. Furthermore, scientists are only rarely exposed to the decision-maker's need to examine the whole problem because the nature of their work frequently leads to fairly narrow specialization. It is of course true that scientists in institutes attached to government ministries are more accustomed to giving "expert advice" and taking responsibility for it than are their colleagues in the more purely academic institutes; the latter have less direct responsibility to the general public and are geared more to peer-group criticism.

In their turn, decision makers must accept the consequences of the way scientific and technological research has been organized in the past. If they want more direct and more immediately useful answers then they must be willing to serve on scientific steering committees to make sure in advance that research findings will be transferrable to their problems. Another problem aggravated by the separation of scientists and decision-makers concerns the optimum allocation of research funds. A great deal of money is at present given to new short-term research projects that have not been coherently developed, rather than being channeled toward existing long-term projects that have a more solid basis. Improved communication between scientists and decision makers and anticipation of future problems to allow a more structured dialogue between the two groups could go a long way toward solving the problems outlined above.

The role of systems analysis is not to duplicate the work of any particular specialized science but rather to fill in the gaps between the approaches of the regulator, the operator, and the scientist, and to knit together these approaches into a coherent whole. Systems analysis can help in resolving conflicts of opinion by asking, structuring, and integrating questions relevant to the entire system rather than just parts of it. The emphasis throughout is on developing (or identifying) a unified system for obtaining better-quality information through better channels and methods, rather than on providing specific advice on particular aspects of the problem.

AUTHOR INDEX

SUBJECT INDEX

MANAGING TECHNOLOGICAL ACCIDENTS: TWO BLOWOUTS IN THE NORTH SEA
Incorporating the Proceedings of an IIASA Workshop on Blowout Management
D. W. Fischer, Editor

A blowout consists of a sudden and uncontrolled release from a well of large amounts of high-pressure gas or gas–oil and carries with it attendant risks of explosion, fire, and pollution; loss of life, equipment, and the hydrocarbon fuel itself are all possible. More generally, a blowout may be characterized as a low-probability, high-risk event which may occur when a complex technological process goes out of control.

Drilling for oil and gas in the hazardous environment of the North Sea has, over the years, given rise to great efforts to improve safety standards and operating procedures. By the mid-70s many observers felt that blowouts in the area were extremely unlikely if not impossible. Nevertheless, 1977 saw two blowouts in the North Sea, one on the *Ekofisk Bravo* platform in the Norwegian sector and the other involving an exploratory well being drilled by the *Maersk Explorer* rig in the Danish sector. The blowouts caused great concern to the general public, to the governments involved, and within the oil industry, and prompted extensive reevaluations of equipment, operating procedures, and the general philosophy of accident prevention.

The management or prevention of such incidents, whose causes lie at the man–technology interface, was the central theme of a Workshop at the International Institute for Applied Systems Analysis (IIASA) which brought together experts on the environment, representatives of the oil industry, and spokesmen for governments and their associated regulatory bodies. This volume is based on the proceedings of the Workshop and is divided into two main parts: the first is an overview of the blowout problem and the second contains the papers presented by Workshop participants.

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