Review of the Interagency Oil Pollution Research and Technology Plan

First Report of the Committee on Oil Spill Research and Development

Marine Board
Commission on Engineering and Technical Systems
National Research Council

REVIEW OF THE INTERAGENCY OIL POLLUTION RESEARCH AND TECHNOLOGY PLAN

FIRST REPORT OF THE COMMITTEE ON OIL SPILL RESEARCH AND DEVELOPMENT

Marine Board
Commission on Engineering Technical Systems
National Research Council

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FOREWORD

Research and development (R&D) related to oil spills follows a boom-and-bust cycle. After catastrophic spills, when the acute effects of oiled beaches, polluted waterways, and dying wildlife are featured in all the media, there is public outcry and political interest, accompanied by calls for action, for more research, and for better prevention and control measures. Later, as acute effects fade, but longer-term and less obvious problems may continue, public interest — and with it political interest — fade. By the time the calls for action are translated into R&D plans, the interest is gone, and the plans typically are neither supported nor funded. When the next catastrophe occurs, everyone wonders why no one has learned more about how to deal with the problem since the last spill.

The phenomenon of cyclical attention and lack of sustained interest and resources, coupled with the natural distribution of research assignments among a group of agencies with different underlying responsibilities, has made it difficult to create a coherently planned R&D program.

Further difficulties for the program have been generated by problems with the regulatory environment in which the research must be carried out.

In response to the mandate of the U.S. Congress in the Oil Pollution Act of 1990, and at the request of the U.S. Coast Guard, the Committee on Oil Spill R&D has addressed these problems and in this first report makes some initial recommendations intended to help with their solution. It is the committee's current view that these recommendations should be addressed, or that the issue of the priority of oil spill research, prevention, and mitigation should be reconsidered.

Robert A. Frosch, NAE
Chairman
Committee on Oil Spill
Research & Development

PREFACE

Research, development, and testing to prevent and mitigate oil spills has been supported by the U.S. government since the late 1960s, when a series of laws protecting the environment were enacted by the Congress. Interest in these activities dwindled during the 1980s, as the number and volume of large spills in U.S. waters declined. In March of 1989, however, the large spill from the EXXON VALDEZ outraged the public and led to calls for an examination of all aspects of the oil spill problem—from prevention to rehabilitation. The Oil Pollution Act of 1990 (OPA-90)(Public Law 101-380) was the Congressional response to the public outcry.

The Act called for an extensive federal oil pollution research and development (R&D) program addressing spill prevention, response, and cleanup.[1] OPA-90 also mandated that the National Academy of Sciences provide advice and guidance for preparation and development of the research plan, assess the adequacy of the plan, and submit a report to the Congress on its assessment. The U.S. Coast Guard, in its role as lead agency for the Interagency Coordinating Committee on Oil Spill Research, requested the advice of the National Research Council (NRC). The NRC appointed the Committee on Oil Spill Research and Development (R&D), which, under the auspices of the Marine Board, was charged with the following tasks:

- to review and assess the interagency oil spill R&D plan and provide conclusions regarding the interagency program and direction as described in the plan,[2]
- to provide recommendations regarding priorities and areas of needed research, development, demonstration of technologies, and evaluation and testing, and
- to account for related R&D undertaken or planned by industry and by foreign research establishments in the assessment and recommendations concerning the interagency plan.

The committee has interpreted its role in reviewing the interagency plan in the broad sense as one of examining the architecture of the plan, its underlying strategy, the major thrusts, and their rationale. The committee did not undertake a project-by-project review. Such technical assessments may be prepared covering areas of potential critical impact on long-range oil spill research planning, but these reviews will be undertaken only on topics identified by the committee or in response to sponsor requests. These assessments may be part of the committee's later reports.

The Committee on Oil Spill R&D is composed of members with expertise in R&D program management, spill response technology for the offshore oil and tanker industries, economics, zoology, the effects of oil pollution on marine ecosystems, systems engineering, ocean engineering and social issues related to disasters. Biographies of committee members are provided in Appendix A. The principle guiding the constitution of the committee and its work, consistent with NRC policy, was not to exclude members with potential biases that might accompany expertise vital to the study, but to seek balance and fair treatment. The committee was assisted by representatives of the U.S. Coast Guard and the Interagency Coordinating Committee.

This is the first of three reports by the Committee on Oil Spill R&D. The primary objective of this phase of the assessment was to review the federal *Oil Pollution Research and Technology Plan*. The committee immediately perceived an absence of systematic or strategic planning logic in the plan. A

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[1] OPA-90 is a comprehensive Act, containing nine titles. Title VII addresses most of the R&D, although Title IV covers some specific studies on prevention that are not included directly in the oil spill R&D program; Title V describes the research program in Prince William Sound, Alaska.

[2] The R&D plan as issued in April 1992 by the Interagency Coordinating Committee is entitled the *Oil Pollution Research and Technology Plan*.

second objective, therefore, was to develop a systems analysis concept as applied to the oil spill system,[3] to aid in the development of a strategic R&D framework for evaluating the plan. Due to the shortage of time and resources available to the committee, the analysis of the oil spill system will be conducted by the Coast Guard during 1993.

The Committee on Oil Spill R&D met three times in 1992. The committee received briefings on the history of federal oil spill research, the evolution of the Interagency Coordinating Committee, research supported by the offshore oil and gas industry, and the plans of the Marine Spill Research Corporation, the largest non-government oil spill R&D organization. In addition, members of the committee attended the International Oil Spill R&D Forum, held June 1-4, 1992 in McLean, Virginia, under the sponsorship of the Coast Guard and the International Maritime Organization (a United Nations organization). Several members of the committee also visited the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) in Leonardo, New Jersey. OHMSETT is intended to be a test center for mechanical cleanup equipment and oil booms; it may have other uses, such as for testing of oil recovery systems and some limited testing of remote sensing systems.

This report is based on the committee's deliberations and review of meeting presentations, as well as papers, discussions, and observations drawn from outside sources, such as the International Forum, and the OHMSETT visit, and reports produced by Marine Board committees on subjects closely related to pollution prevention and spill response.[4] Some sections of this report, however, clearly evolve from the experience of committee members and their judgments regarding fundamental concerns, such as the adequacy of the funding process for multi-year research.

Chapter 1 provides an historical perspective on oil spills in the United States and the need for R&D. Chapter 2 describes the federal plan. Chapter 3 outlines the committee's perspective on the federal plan and describes a systems analytical approach to developing a more coherent and comprehensive plan. Chapter 4 presents preliminary findings concerning strategies for enhancing the substance and effectiveness of the plan. Due to the short time available for review and assessment of the many oil spill research activities worldwide, evaluation of R&D options was limited. Chapter 5 presents conclusions and recommendations drawn from the preceding chapters.

The committee's second report, to be submitted in late 1993, is expected to assess the results of the analysis of the oil spill system, to address intervention strategies in detail, and to use these tools to begin a more comprehensive evaluation of the federal plan. The third report, to be submitted in late 1994, will synthesize all the committee's work and present a complete assessment of the plan, along with conclusions and recommendations from the overall study.

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[3] The term "systems analysis," as used in this report, refers to the generic concept. The application of this concept to the oil spill problem is referred to as the "analysis of the oil spill system."

[4] Marine Board committee reports relevant to pollution prevention include *Human Error in Merchant Marine Safety* (1976), *Research in Collisions, Rammings and Groundings* (1981), *Crew Size and Maritime Safety* (1990), *and Tanker Spills: Prevention by Design* (1991). Spill response reports include *Using Oil Spill Dispersants on the Sea* (1989).

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EXECUTIVE SUMMARY

THE FEDERAL OIL POLLUTION RESEARCH AND TECHNOLOGY PLAN

Although U.S. oil pollution incidents declined in number and volume in the late 1970s and 1980s, the EXXON VALDEZ spill in 1989 led to calls for renewed action to prevent, minimize, and clean up oil spills. The Oil Pollution Act of 1990 (OPA-90) (Public Law 101-380) was the Congressional response to the public outcry. Among its provisions, the Act called for an extensive federal oil pollution research and development (R&D) program addressing spill prevention, response, and cleanup. OPA-90 also mandated that the National Academy of Sciences provide advice and guidance for preparation and development of the R&D plan, assess the adequacy of the plan, and submit a report to the Congress. This report, the first of three annual reports by the National Research Council's Committee on Oil Spill Research and Development, is a response to that mandate.

The federal *Oil Pollution Research and Technology Plan* integrates the R&D projects of 13 agencies and establishes mechanisms for collaboration with industrial and foreign research organizations. The plan defines goals and outlines R&D projects in five priority areas identified by the Interagency Coordinating Committee on Oil Pollution Research: spill prevention; spill response planning and management; spill response technology; fate, transport, and effects of oil; and restoration and rehabilitation. The plan establishes R&D budgets, both for ongoing agency projects in fiscal year (FY) 1991 through FY 1995, and for the additional funding authorized by OPA-90 for FY 1993 through FY 1996.

INITIAL ASSESSMENT OF THE PLAN

In its initial review of the federal plan, the Committee on Oil Spill R&D observed that the domain of each federal agency involved in oil spill R&D has been defined, and that ongoing R&D projects are being coordinated and co-sponsored by the various agencies. In addition, an international forum was held in June 1992, bringing together public and private research organizations from 19 nations and advancing the potential for cooperative programs. The committee concludes that efforts to accomplish most of the R&D planning and coordination goals of OPA-90 have been initiated and that significant progress has been achieved by the Interagency Coordinating Committee.

The committee appreciates the considerable effort that went into developing the federal plan, which addresses many important R&D topics and formalizes a communication network for addressing oil spill R&D issues. But these features, in the committee's judgment, do not constitute a comprehensive structure for addressing the oil spill problem in a systematic manner.

Indeed, the committee concluded from its initial review that the federal plan lacks several important elements of a coherent and comprehensive plan. These elements are (1) an explicit research strategy that is consistent and logical, that defines broad developmental and operational goals and specific objectives to be met in reaching those goals; (2) adequate resource allocation, by federal or external sources; (3) an accountability scheme that assigns responsibilities; and (4) a rational process for analysis and feedback that permits continual reassessment of the plan, encompassing means for gauging the value (both absolute and relative) of individual projects and the likelihood of accomplishing specific goals and objectives.

A basis for full evaluation and further evolution of the federal plan could be provided by an analysis of the oil spill system. The oil spill system encompasses numerous subsystems including all aspects of oil handling and transport processes, spill evolution, and intervention techniques for preventing or minimizing environmental damage. An analysis of the spill system would pinpoint the underlying problems and suggest the most useful solutions. The analysis would produce a framework identifying intervention strategies to prevent, minimize, and clean up spills as well as the R&D required to support these strategies. The framework could serve as a standard to which the federal plan could be compared.

The committee has described the systems analysis concept sufficiently to outline a preliminary framework. However, preparation of a model of the oil transport system, and the analysis of the model, will require time and expertise that are beyond the resources of the committee. These are substantial, complex assignments that require careful attention, because the accuracy of the measure for evaluating the federal plan—and presumably the ultimate effectiveness of the plan itself—depends on the model being realistic, comprehensive, and well supported by the best available data. Therefore:

The committee recommends that the Coast Guard undertake an analysis of the marine oil spill system, which consists of a variety of subsystems beginning with drilling for oil and ending at delivery of the product to the customer. The analysis will lead to an improved understanding of events leading to spills and how actions could affect the cycle of events, particularly those events and their following sequences that damage the environment, and actions that may assist recovery of the environment from such insults. The analysis will provide a basis for maximizing the benefits derived from the federal R&D investment.

In the absence of a such an analysis, the committee has initiated and plans to continue its assessment based on its concept of a coherent and comprehensive plan and on the experience and judgment of committee members.

ENHANCING THE EFFECTIVENESS OF THE FEDERAL PLAN

The committee has sketched a preliminary framework of strategies for intervening in the oil spill system and has reached a number of preliminary findings concerning aspects of the framework. In developing the framework, the committee examined oil spill R&D issues sufficiently to identify a number of important concerns that, if considered appropriately, could enhance the substance and effectiveness of the federal plan.

Important Concerns

Field testing is among the committee's major concerns. Controlled field experiments involving deliberate, limited discharge of oil are essential to progress in certain R&D areas, such as oil dispersants, in-situ burning, incineration, and bioremediation. Laboratory experiments cannot replicate real-world process interactions and variables, and accidental spills provide limited learning opportunities because data on pre-spill conditions and/or spill volume usually are lacking. The committee concludes that field testing and demonstration play a vital role in developing oil pollution response technology and in understanding oil behavior in the marine environment.

Although OPA-90 recognizes the need for field studies, the federal plan does not emphasize these activities. Therefore:

The committee recommends that a program of field testing, as a vital component of an oil spill R&D program, be instituted as part of the federal plan.

The committee recognizes that, at present, such experiments involving intentional spills greater than 1,000 gallons effectively are barred in the United States by the lack of well-defined criteria for evaluating the requests. The relevant regulatory authorities should address this issue.

The effectiveness of the federal plan also could be enhanced by improvements in the decision-making process for spill response. Just as the lack of a well-defined permitting process inhibits experimentation, the lack of clear ground rules for the acceptability of a spill response option makes it difficult to determine what research should be undertaken and undermines incentives for conducting R&D. The effectiveness of oil spill R&D (i.e., the usefulness of results and products) could be enhanced by improving the spill response decision-making process, through the establishment of criteria for the use of various response options—such as burning, chemical dispersants, and bioremediation—for generic habitat types, both on water and ashore. The existence of such criteria is fundamental to response management.

Another constraint on the effectiveness of R&D is the managerial support system for the national and regional spill response organizations. The federal government, even while attempting to coordinate various computerized decision-support systems for oil spills, continues to divide responsibilities and authorities among agencies and spillers during response. Oil spill R&D is of little use unless there is an effective, centralized managerial support system that can acquire, develop, and maintain an understanding of new knowledge and technology to deal with oil spill emergencies.

Public perceptions are another major concern. The committee observes that these perceptions, especially public reaction to oil spills, are a significant part of the overall oil spill problem. Even when public perceptions are not valid scientifically, they are important; public attitudes are, for instance, significant factors in determining whether spill response technologies can be used. The committee concludes that issues of public perception and probable public response (which is to some extent a reflection of public perception) are important and must be understood by the relevant agencies.

The committee recommends that issues of public perception be addressed in an analysis of the oil spill system and in the federal plan.

Finally, coordination of federal R&D activities with those of industrial, university, state, and foreign research organizations is important, particularly in this era of limited resources. Some overlap is to be expected and will be beneficial. But the federal capability to obtain maximum return on R&D investment depends on assurance that projects do not duplicate unnecessarily any past or present activities, and that useful results of industrial and foreign oil spill R&D are applied to U.S. government efforts. Certain parts of the federal plan appear similar to other studies conducted in the United States or abroad. The committee concludes that the Interagency Coordinating Committee needs to continue its efforts to sort out overlap and develop more partnerships with industrial and foreign research organizations. Therefore:

The committee recommends that, as part of the federal plan, a critical review be conducted of past and present oil spill R&D carried out worldwide, to determine the possible application of results to federal efforts and to avoid unnecessary duplication. The committee also recommends that current efforts to foster communication be continued and expanded.

Resources

It is the judgment of the committee that the overall funding level specified in the plan probably will not be adequate to accomplish the tasks assigned to the Interagency Coordinating Committee. As indicated earlier, the wisdom of the fund distribution is difficult to assess at this time, but three areas appear to the committee to have been slighted: prevention (i.e., means to reduce the probability of shipping accidents); restoration and rehabilitation (i.e., the environmental and ecological factors involved in determining, assessing, controlling, and restoring damage caused by oil spills); and human factors and behavior, including the human element in maritime accidents and public perceptions of oil spill issues.

Moreover, the continued evolution and effectiveness of the plan is in doubt because the additional funding authorized by Congress has not been appropriated. For FY 1993 (which began October 1, 1992), the plan called for $11 million for ongoing programs and $19 million[5] for additional R&D under OPA-90.

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[5] OPA-90 authorizes $27.25 million annually for R&D, of which $6 million is designated for regional grants, and $2.25 million for demonstrations projects; that leaves $19 million for discretionary allocation by the Interagency Committee.

The FY 1993 appropriations for oil spill R&D to agencies—such as the Coast Guard, the Minerals Management Service (Department of the Interior), the Environment Protection Agency, and the National Oceanic and Atmospheric Administration—indicate that spill research funding is unlikely to reach the authorized $30 million total. The plan is unlikely to amount to anything more than an incoherent assortment of small projects unless adequate funding is provided. The committee concludes that the effectiveness of the plan, as further developed based on the committee's recommendations, will depend on investment of adequate resources. Therefore:

> **The committee recommends that the Congress and the Executive Branch invest adequate resources to implement the R&D plan.**

A judgment regarding adequacy of funding should be made by the Interagency Coordinating Committee. Sufficient guidance is provided in the *Oil Pollution Research and Technology Plan* of April 1992 to continue ongoing research and to initiate R&D. Subsequent research investment should be guided by the results of an analysis of the oil spill system and the resulting risk reduction/benefit assessments.

1

INTRODUCTION

HISTORICAL PERSPECTIVE ON OIL SPILLS AND THE NEED FOR R&D

The first significant national legislation affecting marine pollution was the Rivers and Harbors Act of 1899 (33 U.S.C. 411-413), but the series of laws reflecting current public interest in limiting pollution of inland and coastal waterways emerged in the late 1960s and 1970s. This was an era marked by the enactment of the National Environmental Policy Act of 1969 and amendments (Public Law 91-190), and the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500). The latter act specifically identified oil as a potential contaminant. About the same time, growth of the world tanker trade and a corresponding increase in the number and volume of tanker accident-related spills led the International Maritime Organization to promulgate the International Convention for the Prevention of Pollution from Ships (1973), and later the 1978 Protocol to the convention (referred to collectively as MARPOL 73/78). These rules, which were adopted or ratified by most major maritime nations, including the United States, specified design, equipment, and procedural requirements to prevent pollution of the sea from oil.[6]

During the 1970s and into the 1980s, considerable research and development (R&D) by the U.S. government, industry, universities, and foreign organizations addressed the needs for systems and technology to cope with the increasing threat of oil pollution. The emphasis was on ship design and strategic decision making, with a view to minimizing the loss of oil during routine operations and as a result of collisions and groundings; some effort also was directed to incident response and spill cleanup. The R&D was productive, but there was no formal, overall scheme; most projects were undertaken on the basis of limited missions or requirements as interpreted by individual government agencies, or to address the needs of a segment of the spill response "market" targeted by a particular company. A research coordination network evolved, but it was mostly informal.[7]

According to the most readily available measures, the combined effect of the various regulatory measures, international agreements (conventions), and R&D efforts may have been beneficial. The number and volume of oil spills in U.S. waters declined from the mid-1970s through the late 1980s. The trend in the number of tanker-related spill events is particularly clear (see Figure 1).[8] During this period, the number of tanker spills declined by 67 percent, barge spills by 42 percent, and non-vessel spills (e.g., from offshore platforms, pipelines, and storage tanks) by 50 percent. The exception to this trend was a 35 percent increase in pollution incidents from other types of vessels, partially due to inland waterway transportation accidents. The trend in volume of oil spilled is not clear; the volume fluctuates wildly from year to year (see Figure 2). The peaks in volume spilled in 1975, 1976, and 1989 can be traced to single

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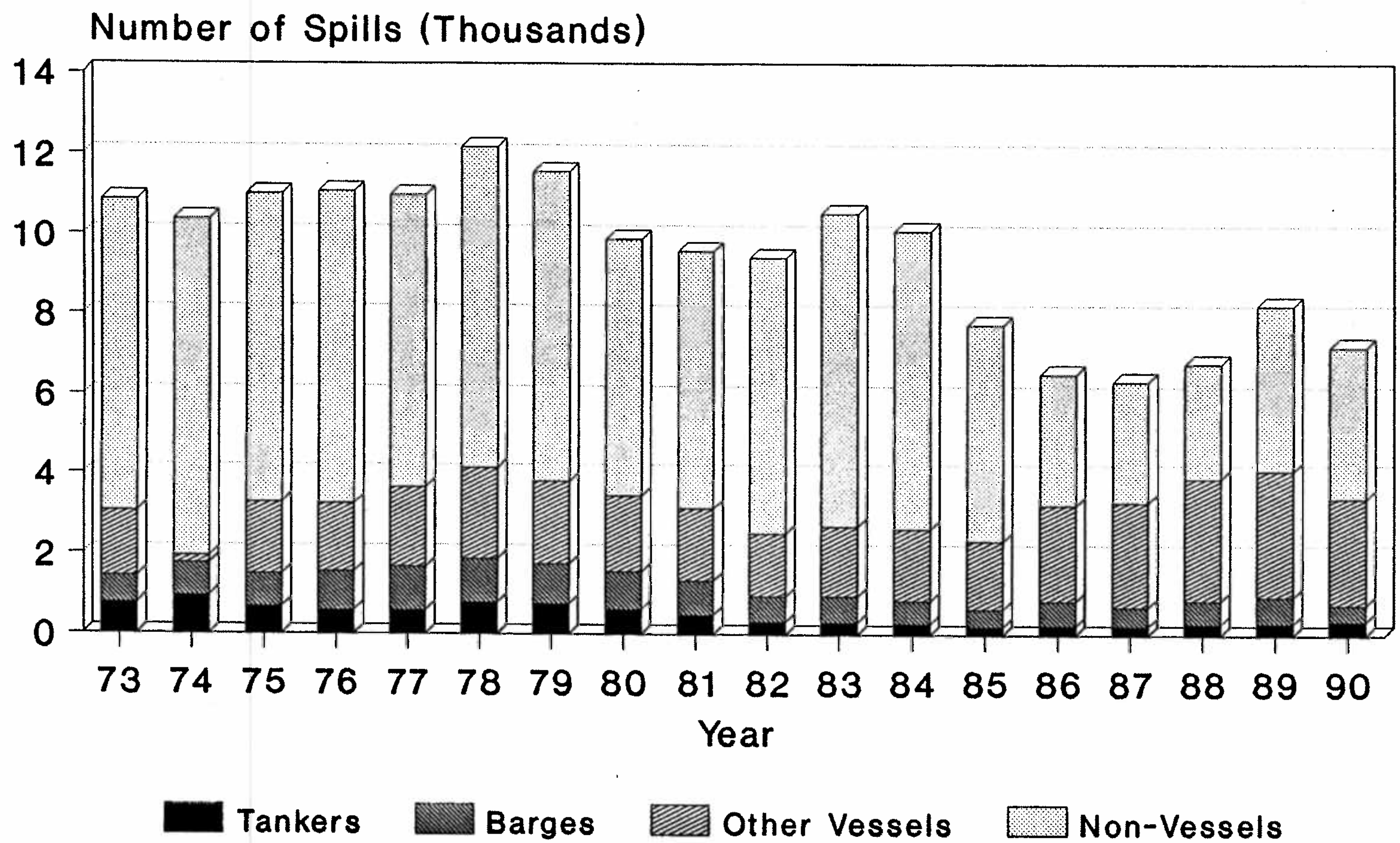
[6] An historical analysis of marine legislation is contained in the Appendix of *U.S. Marine Policies for the 21st Century,* a recent review prepared by the Marine Board. Copies are available from the Marine Board.

[7] Further information about these R&D activities and the network that evolved can be found in the proceedings of biennial oil spill conferences co-sponsored by the American Petroleum Institute, the Environmental Protection Agency, and the U. S. Coast Guard. The first conference was held in 1969.

[8] The decline in the incidence of major spills suggests that human factors are a key consideration, as the recent reduction can be explained, in part, in terms of greater vigilance on the part of the tanker industry, particularly ships' crews. Percentages-of-change in event frequencies and spillage are based on the averages per year for the two sets of years 1973-1978 and 1985-1990.

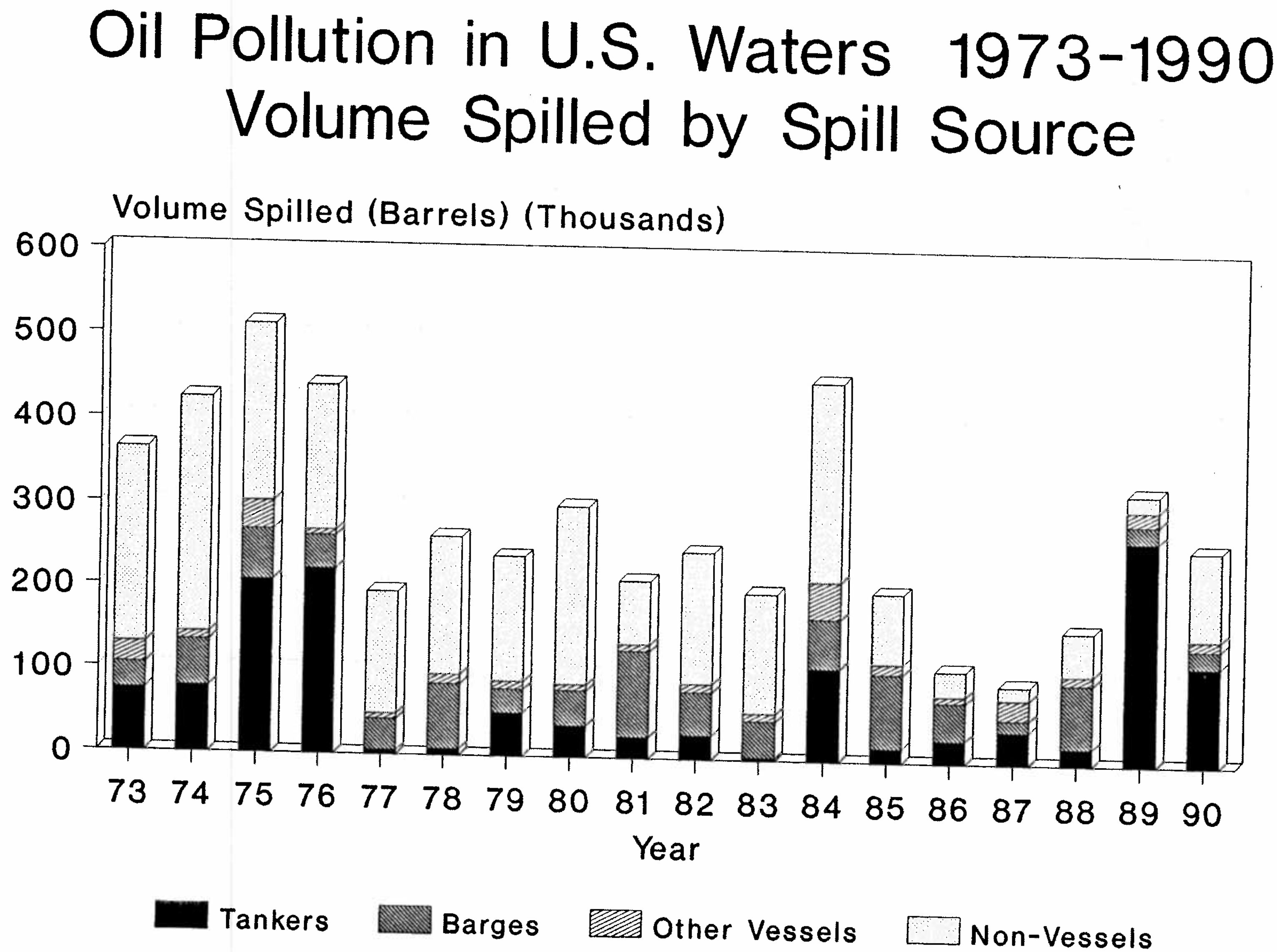
FIGURE 1

Oil Pollution in U.S. Waters 1973-1990
Number of Spills by Spill Source



SOURCE: Minerals Management Service, Department of the Interior based on U.S. Coast Guard Data, February 1992

FIGURE 2



SOURCE: Minerals Management Service, Department of the Interior based on U.S. Coast Guard Data, February 1992 major tanker spills in each of those years.[9] Breakout data on non-vessel spills (50 barrels or more) since 1973 reveal that pipeline and platform spills in federal marine waters constitute a very small portion of total spillage—1.5 percent for pipelines and 0.6 percent for platforms. Moreover, there has been decline in annual volume spilled from oil pipelines and platforms since the mid-1970s, although the average number of these spills has not changed significantly (Minerals Management Service data provided to the committee, September 1992). (Statistics are provided in Appendix B).

These statistics do not tell the whole story. While major spills draw the most attention, small and medium-sized spills occur much more frequently and, in aggregate, have the potential to cause equivalent levels of damage (Garriba, 1992). Variables other than spillage affect the severity and significance of oil spills: persistence in water, coastal and land vulnerability, impact on biota, economic impact (such as on tourist beaches), and regional coverage.[10] The need for more insightful spill information and impact data has been recognized by the Coast Guard and the National Oceanic and Atmospheric Administration (NOAA) in their new efforts to acquire and manage useful pollution accident data.

The need for more R&D to prevent and mitigate oil spills was highlighted in dramatic fashion in March 1989, when the EXXON VALDEZ spilled more than 10.8 million gallons of crude oil into Prince William Sound, Alaska. This event galvanized the public and U.S. policymakers to act on behalf of the environment. The accident also demonstrated the need for greater international cooperation to combat oil pollution.[11] As the U.S. government has acknowledged, "resources for cleanup, the technologies available, and the methodologies used are often marginal" for coping with major spills (Interagency Coordinating Committee on Oil Pollution Research, 1992). Perceptions about the hazards of maritime oil transport were reaffirmed in 1989 and 1990 by three more major spills; two occurred near densely populated areas of the U.S. coast while the third threatened local oyster industries and national wildlife refuges in the Gulf of Mexico.[12]

Despite public and Congressional concerns about spillage from large tanker-related accidents, a serious question faced by the Coast Guard and private spill control organizations—but rarely recognized by the media and the public—is how to balance expenditures between large and small spills. That is, how much effort and resources should be directed toward mitigating unpredictable major spills such as tanker groundings and collisions, and how much toward predictable minor spills at terminals, other oil transfer points, as well as pipelines and facilities within harbors and state waters? These are basic questions that concerned the committee in its review of the federal R&D plan. The committee addresses this point in Chapter 4.

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[9] The CORINTHOS spilled over 8.4 million U. S. gallons in 1975, the ARGO MERCHANT lost 9.5 million gallons in 1976, and the EXXON VALDEZ spilled over 10.8 million gallons in 1989.

[10] An index integrating multiple variables is being developed to measure spill severity and significance. The Marine Oil Spill Scale (modeled on the Richter Scale for earthquakes), a project of the International Energy Agency (IEA), is based on seven variables: spill size, oil persistence in water, oiled water, oiled land, vulnerability of oiled areas, environmental damage, and economic loss. According to the IEA, spill size is not among the most important factors in ranking oil spill events (Garriba, 1992).

[11] Previously, international cooperation in oil spill response had involved bilateral or regional agreements among neighboring countries. To cope with the EXXON VALDEZ spill, the United States requested assistance from "virtually any government known to have or thought to have spill recovery equipment" (Holt, 1992).

[12] The AMERICAN TRADER spilled 300,000 U. S. gallons of crude oil off Huntington Beach, California, and the WORLD PRODIGY lost 289,000 gallons of heating oil at the entrance to Narragansett Bay, Rhode Island. Further from the coast, the MEGA BORG exploded and caught fire in the Gulf of Mexico, releasing an estimated 3.9 million gallons of crude. Most of this oil burned or evaporated, but 40,000 gallons went into the Gulf and affected the Texas and Louisiana coasts.

Recent Actions Addressing the Oil Spill Problem

Congressional concern culminated in the enactment of the Oil Pollution Act of 1990 (OPA-90) (Public Law 101-380). The most important effect of the Act, for purposes of the present report, was the mandate to organize the federal oil spill R&D effort and then to invest in it. OPA-90 established a formal mechanism for cooperation and coordination among federal agencies: the Interagency Coordinating Committee on Oil Pollution Research. The committee includes representatives from 13 agencies.[13] The law also suggested areas for R&D, established regional grants and demonstration programs, and authorized total funding of $27.2 million per year for five years, in addition to funds already allocated for related programs.

Implementation of OPA-90 is intended to cut across federal agencies, and the Interagency Coordinating Committee has been given a broad scope to

- conduct research, development, and demonstration of technologies to prevent or mitigate the effects of oil discharges;
- evaluate and test technologies developed under the interagency program, including the establishment of standards and the use of field testing; and
- conduct oil pollution effects research, including long-term studies of selected spills.

In forming the Interagency Coordinating Committee, OPA-90 established guidelines for preparation of the mandated R&D plan and its implementation. The plan was to be comprehensive in addressing oil spill technology, research was to be leveraged through cooperative programs, program duplication was to be either eliminated or deliberate, and R&D was to be focused in areas of the greatest deficit or need. Beginning in early 1991, the Interagency Coordinating Committee took an inventory of ongoing and planned projects, identified gaps in technical areas, assessed the state of knowledge, established a priority listing of projects, and designated a lead agency for each project or research area. The resulting *Oil Pollution Research and Technology Plan* was submitted to the Congress on April 24, 1992.

In the year and a half since the Interagency Coordinating Committee began its formal work, efforts to accomplish most of the R&D planning and coordination goals of OPA-90 have been initiated and significant progress has been achieved. The domain of each federal agency involved in oil spill R&D has been defined. A plan has been developed outlining the overall federal approach to this R&D and allocating the dollars authorized by OPA-90. Ongoing R&D projects are being coordinated and co-sponsored by the various agencies. Tangible evidence of cooperation is the renewal of Mineral Management Services administered operations at the refurbished Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) in Leonardo, New Jersey; the Navy owns the land where the facility is located and the Coast Guard sponsors much of the research and testing now underway or planned involving booms and skimmers.

In addition, an International Oil Spill R&D Forum was held in June 1992 under the sponsorship of the Interagency Committee and the International Maritime Organization. The forum brought together public and private R&D organizations from 19 nations and helped advance the potential for cooperative programs. To help research managers avoid duplication and find collaborators, the Interagency Committee developed an International Oil Pollution R&D Abstract Database, which as of June 1992 included

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[13] The 13 agencies are the National Oceanic and Atmospheric Administration and the National Institute of Standards and Technology (Department of Commerce); the Environmental Protection Agency; the National Aeronautics and Space Administration; the U.S. Coast Guard, the Maritime Administration and the Research and Special Programs Administration (Department of Transportation); the U.S. Army Corps of Engineers; the U.S. Navy; the Federal Emergency Management Agency; the Minerals Management Service and the Fish and Wildlife Service (Department of the Interior); and the Department of Energy.

reference data on more than 100 funded projects. The database will be updated again in 1993.

Important work remains to be accomplished, however. Although the Interagency Coordinating Committee has established mechanisms for enhancing cooperation with industrial and foreign research organizations, systematic coordination of the federal plan with other, concurrent R&D efforts has just begun. Parallel activities include R&D conducted or sponsored by the Marine Spill Response Corporation (MSRC)—the largest non-government effort with a budget of about $7.0 million in 1993—by industry (oil companies and oil spill cleanup cooperatives), and by universities, where some activities are sponsored by the states of Texas and California. The Interagency Coordinating Committee and the MSRC have met for the purpose of coordination, and there is a clear understanding of each organization's development objectives and plans.

An important unresolved issue is funding. The continued evolution and effectiveness of the plan is in doubt because the additional funding authorized by Congress has not been appropriated. For FY 1993 (which began October 1, 1992), the plan called for $11 million for ongoing programs and $19 million for additional R&D under OPA-90. Initial responses to the U.S. Coast Guard, the Minerals Management Service, the Environmental Protection Agency, and NOAA concerning FY 1993 appropriations indicate that funding is unlikely to reach the planned $30 million total. Moreover, little funding under OPA-90 is expected.[14] (Some funds have been appropriated under the Act, but the equivalent amount has been subtracted from other R&D programs; thus, as of December 1992, the intent of the law with regard to funding had not been satisfied.)

This short-term funding approach poses a significant barrier to most multi-year research. For example, scientists cannot undertake basic research dealing with the nature of oil and sea water mixtures and their response to mechanical and chemical treatment, oceanic environments, and time, because several years of laboratory work and additional time for field testing would be required.

[14] Administrative constraints may limit both funding and technical progress under OPA-90. No specific Congressional subcommittee is in charge of Title VII, and five different committees control or influence the budgets of the 13 agencies represented on the Interagency Committee.

2

THE FEDERAL OIL POLLUTION RESEARCH AND TECHNOLOGY PLAN

DESCRIPTION OF THE PLAN

The *Oil Pollution Research and Technology Plan* contains the following information required by OPA-90: (1) identification of the roles and responsibilities of the 13 agencies involved; (2) assessment of environmental effects from oil pollution and technologies for prevention, response, and mitigation; (3) enumeration of gaps in knowledge and technological deficiencies; (4) research priorities and goals; (5) an estimate of the resources needed to conduct an effective R&D program; and (6) identification, in cooperation with the states, of regional research needs and priorities.

As background, the document describes the events leading to passage of OPA-90, the components of the law, the formation of the Interagency Coordinating Committee, the role and responsibilities of the 13 agencies, and the process for developing the plan. Another section addresses the administration of regional grants authorized under OPA-90. The document also describes federal strategies for coordinating R&D with private and foreign organizations.[15]

The heart of the plan is structured around five priority R&D areas identified by the Interagency Coordinating Committee. The plan outlines available technologies and R&D opportunities in each of the following areas:

- spill prevention (vessel design, operations, and inspection; waterways management; facility design, operations, and inspection; pipeline design, operations, and inspection);
- spill response planning and management (risk assessment and contingency planning; spill response training and readiness; spill management; communications; health and safety; R&D database);
- spill response technology (vessel salvage and onshore/near-shore containment; surveillance; on-water containment, recovery, and treatment; on-water oil treatment; shoreline impact and mitigation/cleanup technology; disposal);
- fate, transport, and effects of oil (transport and properties of oil discharges and byproducts; environmental fate and effects of oil discharges; natural resource damage assessment; identification of sensitive areas at risk; collection of environmental baseline data in areas at risk; preparation of scientific monitoring and evaluation plans); and
- restoration and rehabilitation (methodologies for determining the recovery of oil-contaminated ecosystems; development of environmental restoration methods for sensitive areas).

Five annexes to the plan describe dozens of specific R&D projects in each area. Topics range from vessel structural design to advanced electronics systems to protection of migratory birds. The projects are categorized by funding level to illustrate priorities (see Table 1). Level I projects are ongoing

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[15] As a contact point for states and private groups, the Interagency Committee established a Subcommittee on State and Private Sector Coordination. The Interagency Committee also is working with IMO to implement the International Convention on Oil Pollution Preparedness, Response, and Cooperation of 1990, which was initiated by the United States and signed by 15 nations (subject to ratification) (Holt, 1992). Article 8 of the convention provides for the international exchange of R&D information; the forum held in June was a response to this provision (Interagency Coordinating Committee, 1992).

under existing agency budgets. Level II projects would be conducted if additional funds were allocated in line with OPA-90 authorizations. Other projects not listed in Table 1, but included in the interagency plan as Level III, go beyond the funds authorized in OPA-90. Level III projects are those considered by each agency to be important efforts dependent on additional funding.

The plan establishes R&D budgets, both for ongoing agency projects through FY 1995, and for the $19 million[16] in additional annual funding authorized by OPA-90 for FY 1993 through FY 1996. Table 1 shows how funds are allocated under the plan. Distribution of OPA-90 funds (Level II) for FY 1993 favors spill response.[17]

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[16] OPA-90 authorizes $27.25 million annually for R&D, of which $6 million is designated for regional grants, and $2.25 million for demonstrations projects; that leaves $19 million for discretionary allocation by the Interagency Committee.

[17] Title VII of OPA-90, Section 7001 (f)(1) limits the amount of funding that may be spent on environmental effects research to $3.5 million a year. The Interagency Committee has recommended that this limitation be eliminated, as this type of research not only enables initial assessment of potential harm but also addresses the question of when to stop cleanup efforts -- both key issues.

INTERAGENCY OIL SPILL RESEARCH AND DEVELOPMENT PROGRAM

FISCAL YEAR FUNDING ($K)	LEVEL I 1991	LEVEL I 1992	LEVEL I 1993	LEVEL I 1994	LEVEL I 1995		LEVEL II 1993	LEVEL II 1994	LEVEL II 1995	LEVEL II 1996
SPILL PREVENTION	**4,405**	**3,055**	**2,925**	**1,770**	**1,340**		**3,205**	**5,655**	**4,960**	**3,475**
VESSEL DESIGN	2,010	1,510	910	510	475		1,130	2,005	1,405	1,150
Size & Transp. Requirements	50	50	—	—	—		—	25	50	50
Alternatives Equivalent to Double Hulls	100	50	—	—	—		175	250	175	100
Vessel Stability	100	100	—	—	—		—	—	—	—
Vessel Structure	575	625	310	60	100		350	580	205	100
Propulsion	—	—	—	—	—		—	—	20	—
Maneuvering	160	135	150	—	—		180	350	105	150
Vessel/Equipment Integration & Reliability	1,025	550	450	450	375		425	800	850	750
VESSEL OPERATIONS	470	335	625	475	375		850	1,275	1,150	800
Manning	135	275	550	375	225		750	1,075	900	600
Maintenance & Repair	335	60	—	—	—		25	100	100	—
Cargo Handling	—	—	75	100	150		—	—	—	—
Navigation	—	—	—	—	—		—	—	—	—
Contingency Planning	—	—	—	—	—		75	100	50	100
VESSEL INSPECTION	305	560	360	185	40		50	300	100	100
WATERWAYS MGMT.	1,470	350	680	300	300		400	1,175	405	225
Traffic	1,070	—	—	—	—		150	275	1,200	600
Surveillance	100	100	100	100	100		100	200	250	300
Navigation	200	200	200	200	200		—	—	50	—
Human Factors	—	50	—	—	—		—	—	—	—
Information Systems	100	—	380	—	—		150	700	—	—
FACILITY DESIGN	—	—	—	—	—		100	200	900	300
FACILITY OPERATIONS	—	—	—	—	—		—	—	100	100
PIPELINE OPERATIONS	100	150	150	150	100		425	425	—	—
PIPELINE SURVEYS	50	150	200	150	50		250	275	425	400
									275	200

TABLE 1 (CONTINUED)

INTERAGENCY OIL SPILL RESEARCH AND DEVELOPMENT PROGRAM

	LEVEL I					LEVEL II				
FISCAL YEAR FUNDING ($K)	1991	1992	1993	1994	1995	1993	1994	1995	1996	1997
SPILL RESPONSE PLANNING & MGMT.	**645**	**1,180**	**1,060**	**1,620**	**1,620**	**1,000**	**1,000**	**1,000**	**1,000**	**980**
CONTINGENCY PLANNING	100	400	300	300	200	300	200	100	100	100
TRAINING & PIPELINES EVALUATION	50	80	200	500	500	—	100	300	300	300
SPILL MANAGEMENT	450	600	460	520	520	310	290	180	180	280
COMMUNICATIONS	—	—	—	200	300	100	100	100	100	—
HEALTH & SAFETY	45	100	100	100	100	290	310	320	320	300
R&D CLEARINGHOUSE	—	—	—	—	—	—	—	—	—	—
SPILL RESPONSE TECHNOLOGY	**5,590**	**9,925**	**7,025**	**7,300**	**6,975**	**9,640**	**10,200**	**10,225**	**10,125**	—
VESSEL SALVAGE/CONTAINMENT	300	300	—	—	—	725	725	750	750	—
SURVEILLANCE	900	1,300	1,725	1,450	1,200	1,240	1,800	1,800	1,700	—
Airborne & Satellite	700	1,050	1,550	1,400	1,150	1,240	1,800	1,800	1,700	—
Surface	200	250	225	50	50	—	—	—	—	—
ON WATER CONTAINMENT/ TREATMENT/RECOVERY	1,715	6,625	4,245	5,050	5,100	5,075	5,075	5,075	5,075	—
Containment	—	375	765	1,125	725	525	525	425	425	—
Mechanical Recovery	675	900	50	1,575	1,800	975	975	1,075	1,075	—
Storage	—	200	—	—	—	250	250	250	250	—
Sorbents	110	750	150	250	100	150	150	150	150	—
Standards/Testing/OHMSETT	300	900	1,250	900	1,350	1,025	1,025	1,025	1,025	—
In Situ Burning	430	2,075	1,230	950	950	900	900	900	900	—
Chemical Technology	200	1,425	800	250	175	1,250	1,250	1,250	1,250	—
SHORELINE IMPACT MITIGATION/CLEANUP	2,675	1,700	1,055	800	675	2,500	2,500	2,500	2,500	—
Chemical/Mechanical/Incineration	725	100	55	100	125	1,350	1,350	1,350	1,350	—
Bioremediation	1,950	1,600	1,000	700	550	1,150	1,150	1,150	1,150	—
DISPOSAL	—	—	—	—	—	100	100	100	100	—

TABLE 1 (CONTINUED)

INTERAGENCY OIL SPILL RESEARCH AND DEVELOPMENT PROGRAM

FISCAL YEAR FUNDING ($K)	LEVEL I						LEVEL II			
	1991	1992	1993	1994	1995		1992	1993	1994	1995
FATE, TRANSPORT & EFFECTS OF OIL	**4,595**	—	—	—	—		**3,500**	**3,500**	**3,500**	**3,500**
TRANSPORT & PROPERTIES OF OIL PRODUCTION	480	—		—	—		350	350	350	350
ENVIRONMENTAL FATES AND EFFECTS	—	—	—	—	—		1,500	1,500	1,500	1,500
NATURAL RESOURCE DAMAGE ASSESSMENT	—	—	—	—	—		1,100	1,100	1,100	1,100
IDENTIFICATION OF ENVIRON. SENSITIVE AREAS	75	—	—	—	—		200	200	200	450
ENVIRONMENTAL BASELINE DATA	4,000	—	—	—	—		200	250	250	—
SCIENTIFIC MONITORING & EVAL.	40	—	—	—	—		150	100	100	100
RESTORATION & REHABILITATION	—	—	—	—	—		**1,500**	**1,500**	**1,500**	**1,500**
RECOVERY OF ECOSYSTEMS	—	—	—	—	—		1,230	1,230	1,230	1,230
RESTORATION METHODS	—	—	—	—	—		270	270	270	270

3

EVALUATING THE FEDERAL PLAN

This chapter outlines the committee's perspective on the federal *Oil Pollution Research and Technology Plan* based on an initial review. In the course of this review, the committee defined in concept how it would construct a coherent, comprehensive R&D plan; the elements of the preferred concept are described. The second half of the chapter describes an approach to developing a plan with those features.

THE COMMITTEE'S PERSPECTIVE ON THE PLAN

In examining the federal plan and considering how to assess it, the committee immediately scanned the document for structural elements that, in the collective judgment and experience of committee members, would be desirable in a coherent, comprehensive R&D plan. These elements are: (1) an explicit research strategy that is consistent and logical, and that defines broad developmental and operational goals and specific objectives to be met in reaching those goals; (2) adequate resource allocation, by federal or external sources; (3) an accountability scheme that assigns responsibilities; and (4) a rational process for analysis and feedback that permits continual reassessment of the plan, encompassing means for gauging the value (both absolute and relative) of individual projects and the likelihood of accomplishing specific goals and objectives.

Although the committee appreciates the considerable effort that went into developing the federal plan, which clearly is a useful compendium of relevant projects, it was readily apparent that the elements just defined were missing. The plan identifies specific R&D projects and the agencies responsible for those projects, and it formalizes a communication network for addressing oil spill R&D issues, but these features, in the committee's judgment, do not constitute a comprehensive structure for addressing the oil spill problem in a systematic manner.

The plan describes an overall approach—the five priority R&D areas—but the committee could not discern an underlying rationale for project selection and priorities that would constitute a formal strategy. If there is one, then it is not explicit. The committee did not find textual support for the stated tactic of pursuing an "holistic approach" to R&D emphasizing the interrelationships among machines, workers, and habitats. Moreover, although "goals" are mentioned in the plan, the term is not used in the broad sense preferred by the committee, and no *specific* objectives to be met in achieving those goals are defined. The objectives and programs defined in the plan, rather than arising naturally from an overall strategy, appear to reflect the unique interests of the agencies involved.

With regard to resources, the committee perceives two basic problems: the absolute amount of funding available, and its distribution within the program. At this writing, the federal plan has not been funded at all—no additional money has been allocated in accordance with OPA-90. Even if the resource levels specified in the plan were achieved, their adequacy for achieving the purpose of the plan has not been established. Furthermore, if limited funds originally earmarked for other programs were redesignated for oil spill R&D, it is unclear, due to the absence of a priority ranking scheme, how this amount should be distributed among the various projects. Further analysis will be required to develop a conclusion or recommendation in this area. However, based on the committee's experience and judgment, the overall funding level specified in the plan probably is not adequate to accomplish the task assigned to the Interagency Coordinating Committee. The wisdom of the fund distribution is difficult to assess without a ranking scheme, but three areas appear to the committee to have been slighted: prevention (i.e., means to reduce the probability of shipping accidents); restoration and rehabilitation (i.e., the environmental and ecological factors involved in determining, assessing, controlling, and restoring damage caused by oil spills); and human factors and behavior, including the human element in maritime accidents and public perceptions of oil spill issues. Thus, funding is an important unresolved issue.

The other structural elements favored by the committee—schemes for accountability and continual reassessment—are not apparent in the federal plan in any form.

During its initial assessment of the plan, the committee also made a number of other observations. One concern is balance. The plan appears to favor the application of existing technologies to address shortcomings in response observed during recent large spills. There is less attention to basic research, which is needed to acquire an understanding of the natural phenomena associated with spills and to develop novel methods and technologies. For example, understanding of the transport, fate, and cleanup of oil at sea depends on detailed knowledge of the behavior of oil in the near-surface zone of the sea. This region is marked by highly complicated flows due to wave-generated turbulence and strong wind-induced shear. Research into the nature of these flows and how oil is transported in them is critical to the development of effective cleanup technologies.

On the positive side, in the area of oil recovery, the plan seems to recognize the practical limitations on mechanical recovery of oil at sea: The emphasis is not on technology but on removal of bottlenecks in the overall process (e.g., by extending operations into darkness hours through use of remote sensing and surveillance, and onboard separation of oil and water).

Finally, the committee identified a number of important topics that are not addressed adequately in the plan, including field testing, oil spill response criteria, decision structures for response, public perception and participation, and correlation of the federal plan with R&D sponsored by industrial or foreign research organizations. These concerns are discussed in Chapter 4.

Developing a Coherent and Comprehensive Plan

Although the committee is impressed by the valuable work accomplished in the development of the federal plan, the impression is that this progress has been driven by trial and error. A more systematic approach could provide the basis for identifying points of leverage for improving problem solving and maximizing return on investment. To develop a coherent and comprehensive plan as defined by the elements described earlier, the committee believes an analysis of the oil spill system should be conducted. The following logic would be employed.

The purpose of an oil spill R&D program is to provide new knowledge and technology to improve prevention, protection, and recovery of the natural environment from oil spills and their effects. To protect marine resources and ecosystems (and near-shore land resources and ecosystems), greater understanding is required of how best to manage and, if necessary, to intervene at various nodes in the chain of possible events that may lead to environmental damage from oil spills, and to mitigate this damage when it occurs. To understand how and when to intervene, and to learn what knowledge, technologies, and management systems would be helpful, an analysis is required of the systems involved, their possible failures, and the consequences of these breakdowns. For each failure mode, there should be an understanding of the knowledge, technologies, and actions that might reduce risk of failure and/or that might enable management of the consequences in a satisfactory way to minimize the eventual damage. The overall intent is to identify the points of leverage in the oil spill system, and the means for intervening at these points, that would have the greatest payoff in preventing damage. To do this, the R&D required to provide the missing knowledge and technology must be defined.

Systems analysis is a technique used in many arenas, such as aerospace design, automobile manufacturing, and industrial engineering, to determine the attributes and behavior of a linked set of equipment, processes, and/or activities. The system, as defined for the analysis, must be comprehensive enough to capture all the relevant processes, yet manageable in size; normally, all the elements are circumscribed by a boundary penetrated by specific inputs and outputs. The purpose(s) of such an analysis could be to optimize the system, to predict its behavior, to determine weak points, to identify required technologies, to investigate alternative approaches, and/or to establish costs and schedules. A systems analysis attempts to view a problem in a comprehensive manner, emphasizing the relationships between the parts and the whole; the intent is to discover how changes in one part affect others, and to trace cause and effect—details that could be lost in a piecemeal analysis.

Applying this concept to the oil spill problem, the challenge is to describe or model the oil spill system. This system is defined to encompass a variety of subsystems beginning with drilling for oil, through the production, movement, and handling processes to delivery to customers. Analysis of various possible scenarios in the process would lead to identification of the actions that could be taken to prevent and cope with accidents, to manage spills, and to protect and restore a damaged natural environment. The description should be such that the government and the committee could understand the probability of various events in the possible sequences leading to damage, and how various actions could affect the cycle of events and consequences. Such a model could indicate what R&D should be undertaken to provide the knowledge and technology that would offer the greatest chance of reducing the probability of certain events or minimizing the deleterious consequences of these events.

Such an analysis can be organized by using a model of a tree of events and possible events. The model would be constructed based on documented knowledge about such incidents and additional information that could help depict events and possibilities. Figure 3 is a simplified diagram showing the elements of and inputs to such a model of an oil spill system. The "spill event" boxes and arrows indicate some of the nodal points for events that, if they occur, will produce new trees of events. Each of these trees would need to be developed fully, through the eventual possible fates of the oil and the possible environmental effects. The analysis would need to examine the possible effectiveness of intervention and action at various points in each of these trees. This chain of analysis then could be used to test the possible value of additional knowledge and technology in preventing ultimate damage to the environment. Factors that must be considered include the value of various appropriate mechanical and procedural systems and specific types of biological and ecological knowledge in assessing and controlling damage, and the human behavior and perception aspects of spills, environmental damage, and various intervention activities. (The safety of people and property is included implicitly in the environmental damage analysis.)

Beginning with the "phases of intervention" in Figure 3, strategies to support implementation of new systems and intervention to reduce risk would be identified, as would the R&D needed to support those strategies. This framework of strategies would be used to establish R&D priorities, which could be employed as the technical elements of a coherent plan. The framework also could serve as a standard for evaluation and continued evolution of R&D projects or plans, such as the federal *Research and Technology Plan*. The framework concept is discussed further in Chapter 4.

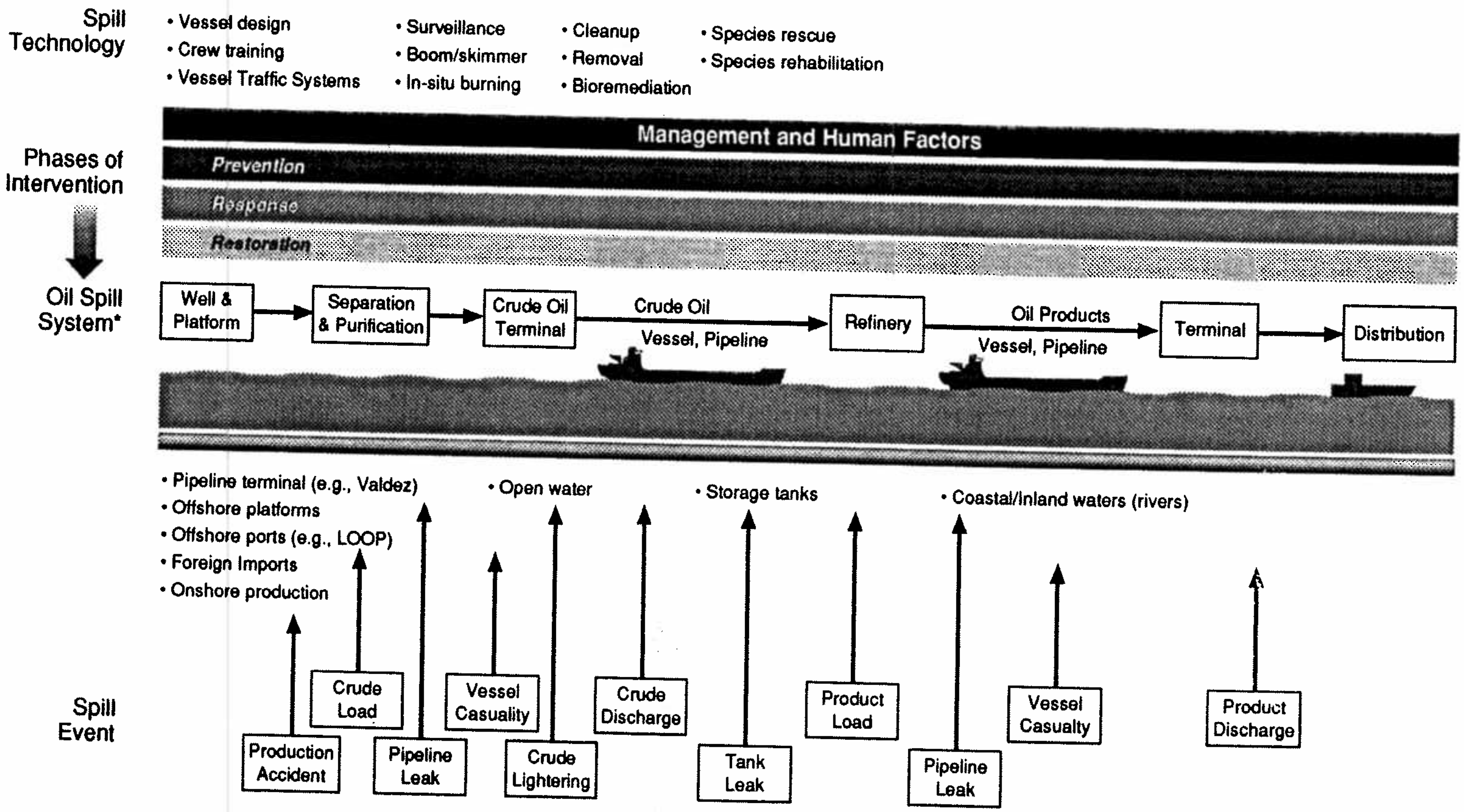
In analyzing the oil spill system, it would be important to avoid becoming mired in the sequence analysis, but to develop an adequate foundation to weigh options. For example, in an oil spill case, responders need to weigh active defense of a shoreline, or the most sensitive part of a shoreline (e.g., by use of mechanical skimming, chemical dispersants, or burning), versus deploying booms to dam or divert the spill itself and thus prevent movement of oil to a sensitive ecosystem. The analysis is not an end in itself; it should be pursued only to the level of detail such that the results provide useful guidance in understanding the relative values of various kinds of knowledge and technology that could be pursued.

The committee has developed the concept of the analysis of the oil spill system sufficiently to outline a framework of intervention strategies. However, preparation of the spill system model, and the analysis of the model, will require time and expertise that are beyond the resources of the committee. These are substantial, complex assignments that require careful attention, because the accuracy of the measure for evaluating the federal plan—and presumably the ultimate effectiveness of the plan itself—depends on the model being realistic, comprehensive, and well supported by the best available data. Therefore, it would fall to the Coast Guard to arrange for preparation of the model.

Any of a number of systems analysis methodologies could be used to establish a coherent R&D plan. An example of one methodology, including standard principles for developing the model, is provided in Appendix C. This sample methodology is judged by the committee to be appropriate, reasonable, and likely to lead to the desired result. The methodology is broken down into four phases: statement of the problem, analysis, alternatives and reformulations, and synthesis. The first phase includes development of

Figure 3

OIL SYSTEM MODEL (Concept)



* *System elements include production, processing, transmission, storage, transportation, and distribution subsystems.*

the spill system model, and identification of distinct segments of the process. The analysis phase involves analyzing the model to locate risk points, to rank them according to importance, and to assess possible measures for preventing, eliminating, or mitigating consequences. The next phase involves identifying process alternatives that could eliminate or minimize risk and consequences, and then repeating the analysis phase for each alternative. The final phase involves synthesizing the results of the modeling and analysis processes, to establish an R&D framework with specific goals and objectives, and to develop a series of strategies for achieving the goals.

4

ENHANCING THE EFFECTIVENESS OF THE FEDERAL PLAN

As discussed in Chapter 3, an analysis of the oil spill system could provide a basis for a complete evaluation of the federal *Research and Technology Plan.* In the absence of such an analysis, the committee has initiated its assessment by developing a preliminary framework of intervention strategies that could provide a basis for a more coherent and comprehensive R&D plan. This chapter outlines the framework and a number of findings, based on the judgment and expertise of committee members, concerning certain aspects of the framework.

In outlining the framework, the committee examined oil spill issues sufficiently to identify several important concerns that, if considered appropriately, could add to the substance and could enhance the effectiveness of the federal plan. The second half of the chapter discusses these concerns, which are field testing, oil spill response criteria, decision structures for response, public perceptions and participation, and coordination of the federal plan with industrial and foreign R&D.

THE FRAMEWORK: STRATEGIES TO REDUCE RISK

The systems analytical approach to the development of an R&D plan suggests to the committee that it would be useful to sketch a framework of possible strategies for intervening in the oil spill system. This exercise demonstrates the utility of the framework approach, which can guide the government and the committee in fulfillment of their tasks and, when completed, can serve as a standard for evaluation and evolution of the federal plan.

In the committee's judgment, the overall basis for the framework—and a sound R&D plan—should be the goal of minimizing or eliminating environmental degradation. Even though the number and volume of spills appear to be decreasing in U.S. waters, experience suggests that, without fundamental and far-reaching changes, these events will continue to occur and that environmental damage and perceptions about it will remain important and driving issues. The effects of uncontrolled releases of oil are, in many cases, uncertain, but they are believed to be potentially severe and, therefore, best reduced or eliminated. Thus, the principal strategic objective of an R&D plan might be to prevent accidents in the first place. Cost is a key concern: The economic consequences of environmental damage due to spillage are believed to be substantial (e.g., the loss of one year of production from Prince William Sound fisheries), if uncertain, and, equally important, the costs of current methods of mitigating damage, restoring the environment, and disposing of the collected residues also are significant. The latter costs cannot be ignored; however, the committee believes that judgments and decisions should not be based solely on the economics of the oil industry.

The committee elaborated on the overall purpose as follows: The primary goal of an oil spill R&D program should be to expand the knowledge base (including the basis for practical implementation) and to develop technology to minimize damage to ecosystems, private resources, assets, and facilities. The ecosystems of chief concern are usually aquatic and coastal. These ecosystems support a wide range of plants and animals, provide habitats for endangered and highly valued species, and support commercial and non-commercial activities such as fishing, mineral recovery, and aquatic recreation. Other resources that may be affected include public and private properties, such as harbor facilities and beaches, and aesthetic attributes. Furthermore, spills may threaten the health not only of animals and plants, but also of humans who live nearby and/or are employed in oil transport and cleanup. Several spills have occurred during tanker collisions, but fortunately few that have occurred in U.S. waters resulted in major spillage with fires.[18] Even when health problems are not a direct consequence, noxious odors and oil residues may remain.

To meet the overall goal of minimizing or eliminating marine degradation, two objectives must be achieved. The first objective is to expand the knowledge base used or needed to minimize or eliminate damage to the ecology, and to public and private marine resources. There must be an understanding of the phenomena and ecological systems characteristics that will enable preventive measures and corrective measures to be applied. The scientist needs to determine what elements of the natural world may have a significant impact on prevention, response, and mitigation. The scientist also needs to understand the processes and evolution of a spill and the effects of oil on ecosystems over various time scales. This understanding is only partly extant.

The second objective is to expand the scientific and technological basis for applying practical measures to reduce or eliminate the probability of spills, to mitigate the consequences of spills, and to restore the environment to its former natural state, or at least, to a condition meeting "positive" and "acceptable" criteria. This objective must build on the accomplishments within the first objective—an expanded knowledge of marine phenomena and ecological systems—to create the foundation for improving oil handling processes, enhancing the reliability of human and equipment/facility components of the oil spill system infrastructure, and fostering mitigation and restoration processes. In addition, a scientific basis should be established for selection of appropriate mechanisms to provide spill response and mitigation action in a timely fashion.

With the stated goal and objectives and a rudimentary model of the oil spill system in mind, the committee determined the major elements of a framework as outlined in Table 2. (The left-hand column of the table corresponds to the "phases of intervention" in the model of the oil transport subsystem presented earlier in Figure 3). For each phase of activities, general types of intervention opportunities are identified. The third column provides specific examples of intervention strategies, including R&D to support those strategies. These examples are intended to convey the manner in which the framework can lead to an R&D strategy that can be used to guide the rational evolution of the federal investment plan.

[18] The BURMAH AGATE accident off the Gulf of Mexico coast in 1979 was the largest accident of this type. It resulted in the loss of over 12 million gallons of crude oil, most of which burned.

Table 2 Preliminary Framework

Phase	Opportunities for Intervention	Examples of Intervention Strategies (including supportive R&D)
Management & Human Factors	Regulatory and Management Structure	Base structure on research into emergency response principles, incident experience, and human behavioral data. Include public in decision making regarding technology development and criteria for its use.
Planning and Prevention	Strategic Plan	Develop strategic plan based on model of oil transport system and specific objectives (both onboard and on shore).
	Decision Support System for Operation Planning and Management	Establish decision support capability to aid in response; include databases on environmental effects of spills, handling of various oil types, contingency plans, equipment availability, etc.
	Prevention of Incident	Design transport system, equipment, operational procedures, and training programs to minimize risk.
	Limitation of Discharge	Design onboard equipment and procedures to limit discharge. Establish response equipment and procedures on shore.
	Passive Defense Against Discharge	Identify sensitive potential targets of spills at sea and on shore. Develop and implement post-spill protective measures.
	Recognition and Evaluation of Incident	Develop on-board and off-board sensors to detect spills. Establish automatic reporting systems for spill incidents.
Response	Control and Mitigation	Contain, remove, alter, or decompose oil, or take no action. Restore species or not.
	Monitor and Evaluate	Determine status of spill and damage. Evaluate cost and social effectiveness of response. Decide when to terminate response.
	Minimization of Consequences	Identify spill direction and targets. Pursue passive defense measures, shoreline treatment, and oil disposal.
	Removal of Discharge Residue and "Sanitization"	Treat residue by physical or chemical means, or remove and bury or incinerate it. (Requires R&D to determine most effective treatment measures under different conditions.)
	Monitor and Evaluate	Determine status of spill and damage. Evaluate cost and social effectiveness of response. Decide when to terminate response.
Restoration and Response	"Restoration" to Prior or to New State	Assess technical, cost, and social criteria to determine desirable extent of restoration.
	Monitor and Evaluate	Determine status of spill and damage. Evaluate cost and social effectiveness of response. Decide when to terminate restoration. Monitor long-term status of environment.

Preliminary Findings for Each Phase of Intervention

In developing Table 2, the committee arrived at a number of preliminary findings, which are based on presentations and deliberations carried out at meetings and on the expertise and experience of committee members. The following discussion addresses some, but not all, key issues that are likely to arise in a more complete assessment of the interagency *Oil Pollution Research and Technology Plan.*

Management and Human Factors

Human error has been identified in many industries as a major cause of accidents, and it is a critical problem for the maritime industry (National Research Council, 1976, 1981, 1990; National Transportation Safety Board, 1981, 1990). Considerable precedent has been established in the aviation, defense, and nuclear industries for the application of human factors analysis to issues of human performance. Three major points can be drawn from the research literature on the role of the human element in industrial contexts:

- The human element, as reflected by human error, accounts for a significant proportion of all accidents and incidents—usually over 50 percent. The figure is about 80 percent in the maritime industry (Interagency Coordinating Committee, 1992; Levy, 1992).
- The causes of human error are numerous: mental lapses, poor human-machine interfaces, poor job design, poor staffing and training, inadequate supervision, and ineffective organizational design, to name a few.
- The human contribution to risk comes not only from the factors driving the frequency and consequences of human error, but also from the organizational systems designed to reduce the likelihood of error *and* to improve on the basic design of the system itself. Thus, improvement processes at organizational/management levels must be addressed along with human error at the individual level.

Over the years, the concept of human factors has been expanded to include many issues. Among the issues relevant to oil transportation are

- person-machine interface specific to oil transportation and spill response;
- human performance in extreme situations, including extreme environmental conditions;
- job design, job aids, supervision, and training;
- organizational, team, and leader performance related both to the prevention of accidents and to spill response; and
- the societal context within which shipping practices are formulated and oil pollution is regarded, including regulations, standards, and public response.

The Coast Guard has convened a Human Factors Coordination Committee (in the Office of Marine Safety, Security and Environmental Protection) and has initiated both national and international efforts to encourage serious consideration of human factors principles in the design, operations, maintenance, and organization of the marine transportation system. These efforts focus on the shipboard and crew aspects, particularly in respect to crew fatigue and the person-machine interface. The Coast Guard also contracted with Battelle Northwest Laboratories in 1992 for the development of a human factors research plan for identifying and solving marine safety problems. This work is expected to be completed in mid-1993. These are important steps toward identification of research issues related to oil pollution prevention and response.

Planning and Prevention

The committee plans to devote considerable attention to this phase, as spill prevention may offer the most leverage of any intervention strategy and may cause the least environmental harm. Although the cost and practicality of systems intended to prevent spill-causing events remains uncertain, the committee believes that prevention deserves significant emphasis in an analysis of the oil spill system. The federal plan concentrates on post-spill response.

The basic technical elements of prevention and planning include: improved knowledge and control of ship positions relative to potential hazards; development and implementation of an integrated, strategic oil spill decision-support system; communications, information transfer, and surveillance; and limitation of discharge from ships and pipelines. Many of the measures that could be employed during this phase (e.g., ship and pipeline design, automatic tracking of vessel movements and spill response units) require development and application of existing technology, rather than basic research.

Response

This is a complicated phase, given that a response is appropriate, because response efforts must be mounted on so many fronts, and so many response options are available or plausible. The basic technical challenges include limitation of discharge from ships, platforms, and pipelines; control and mitigation on the open ocean, in bays and estuaries, in fresh water, and on shorelines; collection of oil; and disposal of wastes.

Considerable effort will be required to answer the many questions remaining about response options. For example, to limit discharge from ships, several prototype booms have been designed for automatic deployment from tankers after major accidents. Tests undertaken to date have not been at sufficient scale to demonstrate effectiveness, nor have they been conducted under conditions that simulate emergency operations. Booms of any type are likely to have limited application because they have not been successful in currents greater than one knot and in wave heights over six feet. Development efforts underway may extend this capability to 1.5 knots and higher seas (U.S. Congress, 1990).

Restoration and Rehabilitation

The strategies and tactics of spill response are developed primarily to mitigate the environmental effects of spilled oil. These effects can occur before, during, and after the oil reaches the shoreline. These effects, and the subsequent recovery of the aquatic and shoreline environment, are functions of a complex set of exposure (i.e., oiling), biological, geomorphological, and other factors. The fate and behavior of the released oil are linked to these effects. Choices of response methods often represent trade-offs between potential effects. The choice between chemical dispersants and surface containment explicitly involves balancing water column effects versus water surface and shoreline effects.

For example, in shallow areas, where limited water or flow is available to dilute the dispersed oil to less than lethal concentrations, organisms will be impacted severely by dispersed oil. However, while some immediate biological effects of dispersed oil may be greater than for untreated oil (which would tend to remain on the surface), long-term effects on most habitats, such as salt marshes, sea grasses, and mangroves, are less, and these habitats recover faster if oil is dispersed before it reaches these areas (National Research Council, 1989).

The natural "recovery" of biological resources can be accelerated by scientifically valid and targeted restoration and rehabilitation strategies and by rescue actions taken before spilled oil reaches a critical system. Decisions related to the mitigation of biological impacts, the assessment of effects, and the restoration and rehabilitation of habitats and biota require information derived from both short- and long-term research. Key information/research needs can be expressed by the following questions:[19]

● What are the relationships of mitigation/cleanup methods, intensity, and duration to biological effects?

Research issues include

• definition of the risks of various cleanup options to various habitats in different climates versus the benefits and trade-offs;

• establishment of the link between contaminated habitat to biological health; and

• definition of cleanup "end points" using expertise in both biology and social science.

● When is a biological system or species "recovered"? What are the endpoints by which to judge when the influence of a spill is over?

Research issues include

• definition of a healthy or restored ecosystem in both scientific and social contexts;

• development of accepted, valid methods and tools for measuring recovery; establishment of rates of recovery; and

• exploration of the concept of recovery as it relates to chronic, long-term impacts.

● When should a species be rescued, rehabilitated, and repopulated, and a system or habitat restored?

Research issues include

• exploration of the social and biological aspects of the rescue, cleaning, rehabilitation, maintenance, and release of endangered animals and plants; and

• development of guidelines for whether and when to reintroduce or enhance a population versus accepting a habitat's altered state and allowing natural processes to reign.

● Is a purposeful response or intervention more effective than "doing nothing" and, if so, under what circumstances and with what methods?

Research issues include

• assessment of the basic impacts of pollution and "natural" ecosystem responses;

• understanding of short-term biological evolutionary processes; and

• evaluation of the impacts of particular climates, weather, oceanography, ecosystems, and other variables.

IMPORTANT CONCERNS

In developing the preliminary framework, the committee identified a number of important concerns that influence the effectiveness of an oil spill R&D program. Some of the related issues have yet to be resolved; indeed, some may be sufficiently complex that a full analysis is beyond the means of the committee. Nevertheless, the committee believes these concerns to be worthy of consideration. Following is a summary of the committee's analysis of these topics, which are field testing, oil spill response criteria, decision structures for response, public perception and participation, and coordination of the federal plan with industrial and foreign R&D.

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[19] It is assumed that biological impacts will occur regardless of the degree of spill prevention and cleanup effectiveness.

Field Testing

Field experiments (i.e., controlled releases of oils in different habitats) are an essential element of any oil spill R&D program. Studies involving controlled and instrumented experimental releases provide research-quality data; input factors can be controlled, and pre- and post-spill variables can be measured. (Real-world experiments and tests are routine in industry; actual automobiles, for example, are crash tested.) Apart from field experiments, there are only two alternatives for acquiring research data. Small-scale laboratory experiments cannot replicate real-world process interactions and variables. The second alternative is to take measurements during accidental spills (also referred to as "spills of opportunity"), but these measurements provide limited information because data on pre-spill conditions and spillage volume usually are lacking. Moreover, it is seldom possible to have equipment and researchers available in a timely manner, nor are transportation and logistics readily available to the scientist; supporting assets are focused on the emergency.

Field experiments have been conducted to test spill response technologies and to explore basic questions about oil fate and effects. In the late 1970s and early 1980s, field tests with dispersants began in Britain and also were conducted in France, Norway, Holland, and North America; over a 10-year period, more than 100 test slicks were laid out in 26 separate field trials (Thornton et al., 1992). Japan, as part of its studies on oil fires, conducted a test burn at sea in 1969 to measure radiation, scale, and burning rate (Koseki, 1992). A few field tests have been approved in Australia (Brodie, 1992). Today, field tests are common in Canada and Norway, where the emphasis is on basic research. The Canadians continue to monitor the fate of oil from the Baffin Island Oil Spill (BIOS), an experiment conducted a decade ago, and to make use of accidental spills for exploration of weathering, long-term effects, and oil fate (Fingas, 1992).

In the United States, however, researchers are unable to obtain the exemptions needed to conduct field experiments with oil dispersants or in-situ burning. The last federally approved experimental spill was in 1979. This spill, conducted off the coast of Southern California to evaluate the performance of dispersants, involved 9 to 20 barrels of crude oil for three tests (McAuliffe et al., 1981). Since then, funding for this type of testing has been discouraged and has been redirected abroad, because deliberate discharges greater than 1,000 gallons (23.3 barrels) effectively are barred. The major barrier is the lack of well-defined criteria for evaluating exemption requests, a duty assigned to the Environmental Protection Agency (EPA). (In the past, one or two officials have reviewed exemption requests; the agency now is forming a review committee.)

As of June 1992, two applications had been submitted to the EPA to allow controlled releases of oil for experiments with in-situ burning; neither burn was conducted because the permits were not approved in time to schedule the logistics. The EPA stated that neither application contained enough information to be court defensible. Four problems were identified: (1) lack of clear permit application guidelines (the existing guidelines were established in 1971); (2) lack of clear definition of the steps involved, including the chain of command, in securing a permit; (3) lack of clear definition of the information required in permit applications; and (4) the lack of timely two-way communication between the EPA and the applicants.

The barriers to field testing appear to be inconsistent with the intent of OPA-90, which in subsection 7001 (c)(30)(c) permits controlled field testing, although it does not specify that such experiments can be done with oil. In the committee's judgment, the risks associated with a small experimental spill probably are small compared to the knowledge that could be gained. The lack of new knowledge gained in this way is making it difficult to improve decision making during emergency response. Without controlled experiments, little progress is likely in certain R&D areas, such as oil dispersants, in-situ burning, incineration, and bioremediation. Indeed, the goals of Title VII of OPA-90 cannot be met without this type of research.

Attention to this topic could enhance the substance and effectiveness of the federal plan. The scientific and technical value of field testing could be emphasized in the plan and the barriers to execution of these studies could be addressed by the relevant authorities. One approach to removing the regulatory barriers could be to establish specific criteria for the approval of experimental spills and to institute a process for efficient (i.e., timely) review of proposals to conduct field experiments; if a proposal met the criteria, then the request would be granted.

Oil Spill Response Criteria

Just as the lack of a well-defined permitting process inhibits experimentation, the lack of clear ground rules for the acceptability of a spill response option makes it difficult to determine what research should be undertaken and undermines incentives for conducting R&D. For example, present shoreline treatment matrices are too general and noncommittal to serve as definitive guidelines, in part because virtually all knowledge accumulated to date is empirical. In addition, allowable R&D varies by region; the use of techniques such as dispersants or in-situ burning depends largely on the philosophy of the regional response team. Even when an option is permitted by statute, that option may be disallowed or even prohibited in practice.

Researchers need to know the criteria that define the boundary conditions within which a response option may be applied. If a response technology is not likely to be approved, then purchase and stockpiling of related resources are unlikely. Moreover, R&D related to that technology is discouraged; studies of techniques that *might* be acceptable are not likely to be a high priority.

The effectiveness of oil spill R&D (i.e., the usefulness of results and products) could be enhanced by improving the spill response decision-making process through the establishment of criteria for acceptable response options for generic habitat types, both on water and ashore. The impacts of particular types of response options would be considered as a basis for establishing rational criteria. The existence of such criteria would focus development on pre-accepted response options. Indeed, such a mechanism is fundamental to effective spill management. For example, availability and stockpiling of dispersants and their application equipment are dependent on pre-approval of dispersant use in specific habitats. It might be useful to focus on developing a standardized "kit of tools" that could be used for spill remediation.

Research and analysis would be required to develop a systematic, consistent decision mechanism for response management. The approach might involve (1) definition of onshore substrate/habitat types, using a realistic matrix that closely parallels real-world coastal characteristics in all their complexity (Louisiana alone has 16 major categories of shoreline [Karolien-Debusschere et al., 1991]); (2) identification of the best set of techniques for each situation in terms of effectiveness (i.e., efficiency plus effects); and (3) R&D projects to explore and evaluate those options.

Decision Support for Response

Another management issue that constrains the effectiveness of oil spill R&D is the managerial support system for the national and regional spill response organizations. During the past decade, considerable progress has been made in developing technology to support spill response. These decision-support systems can provide real-time information to a response director/coordinator.[20] A variety of systems are used in the United States; there is no central system shared by all the actors in spill response, although input data is exchanged. The Coast Guard, the National Oceanic and Atmospheric Administration (NOAA), and the Fish and Wildlife Service are in various stages of developing independent but coordinated systems (Interagency Coordinating Committee, 1992). Some U.S. oil companies and the Marine Spill Response Corporation (MSRC) have developed systems as well. The private groups either invest a minimal amount, assuming the Coast Guard/NOAA technical information and data systems will support response needs, or they develop unique systems based on internal needs or

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[20] The most advanced systems integrate databases (for cleanup equipment, environmental resources, spill experts, etc.) with oil spill trajectory and fate models, spill response models, natural resources damage assessment models, and real-time data-gathering techniques.

as independent checks on the government systems.

The key problem in designing and implementing such systems is to define clearly the organizational structure and operational procedures used for spill response. A decision-support system is *not* a substitute for an effective operational management structure. Definition of structures and procedures is a standard principle of emergency management, as exemplified by fire-fighting units. But the federal government, even while attempting to coordinate decision-support systems for oil spills, continues to divide responsibilities and authorities among agencies and spillers during response. Oil spill R&D is of little use unless there is a managerial system that can deal with spill emergencies, and unless the individuals working in that system can understand and be prepared to use the knowledge and technology derived from the R&D.

The Coast Guard is authorized, in navigable waters, to coordinate and direct federal pollution control effects. If cleanup response is not deemed adequate, Coast Guard authority may be extended to cover pollution control activities of spill response organizations, including those under contract to the spiller, who has initial responsibility for cleanup.[21] In the aftermath of the EXXON VALDEZ accident, the Coast Guard revised the on-scene emergency management structure set forth in the National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR 300), but the new scheme has yet to be tested in a real emergency (Coast Guard presentation to the committee, September 22, 1992).

The new federal on-scene command structure and procedures could be monitored to determine if they improve spill management and increase the probability of effective usage of improved methods and technology derived from R&D. Depending on the results, a systematic evaluation could be conducted. Components of such an evaluation could include: a comparison of the structure and procedures to the highest principles of practice in emergency management, a link analysis of the conduct and perceived effectiveness of liaison among responding organizations, observation by an independent evaluation team at various operation points during actual spill response, and development of a mechanism for inter-organizational review of the evaluation team recommendations.[22]

These evaluations, and possibly other inquiries and tests stemming from an analysis of the oil spill system, could contribute to the evolution of the federal R&D plan.

If warranted, the U.S. government could develop a unified federal on-scene command structure and associated procedures for directing spill response. Once this organizational problem were solved, an effective decision-support system could be constructed (using existing hardware and software capabilities). The lead agency could establish standards for data transfer among private and government agencies (both domestic and foreign); such standards would improve overall data quality and facilitate data exchange. The combination of a unified command structure and an effective decision-support system would maximize the effectiveness of oil spill response technologies, and thus would ensure the highest return on R&D investment.

Public Perception, Response, and Participation

The organization of the oil spill system is shaped by the larger socio-political context. One element of this context is the perceptions of various interested "publics" (e.g., individuals, the Congress, the

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[21] Coast Guard costs are reimbursed, either from the Oil Pollution Fund or by the party responsible for the spill. Up to $50 million a year is available from the emergency fund.

[22] Variables of concern include mechanism for transfer of authority; differences in demands on the emergency management structure for medium versus large spills; information relay among responders; use of decision support systems; implications of natural damage assessment requirements for emergency response coordination; training and drill needs; approaches for differentiating between weaknesses in procedures and performance; and costs and benefits of developing continuity in response teams.

oil industry, or any organized special interest such as environmental groups) concerning transportation practices and oil spill response. In recent years, public concern and distrust have become evident in this arena. For example, some 60 percent of the 5,000-plus letters received by the Coast Guard since the EXXON VALDEZ accident reflect the feeling of trust betrayed (Coast Guard presentation to the committee, September 22, 1992).

A major reason for conducting R&D on a technology is to have some assurance of effectiveness. Besides the technical consideration of whether a particular technology does what its developers claim, other considerations are related to whether the technology is consistent with public values, such as concern about further environmental damage or the financial cost associated with its use. Decisions regarding whether to use a certain technology, and the development of standards and technology for when it is used, must be addressed as policy issues rather than as technical issues.

In arenas other than oil transportation, environmental management has evolved to permit public participation in important decisions. Public acceptance appears related to the extent to which interested publics can be involved, either in decision making about the criteria for technology use, or in discussions about the trade-offs considered central to the deployment of new technologies. Public acceptance is an element in the development of oil spill planning and response management and is, therefore, a consideration in the development of an R&D strategy. Public response to past spill events and clean up and prevention strategies should be considered as part of the analysis of the oil spill system. The federal plan should include resources and mechanisms for public participation to assure that the various stakeholders in the oil transportation and spill response process have an opportunity to make their concerns and preferences about trade-offs known to those who establish policy on how best to address current problems with the overall oil spill system. Mechanisms for conveying public concerns and preferences can include public hearings, conferences and workshops, establishment of standards review and other advisory and review groups, and the development of cooperative agreements and referenda.

Because all technologies have some costs or impacts as well as benefits, it is not uncommon to find some segment of the public disagreeing with an ostensible scientific conclusion that the use of a given technology is totally congruent with the public interest. Thus, provisions for exchanges between experts and stakeholders that make the trade-offs evident and help to build consensus can be important elements in developing policies about the use of certain technologies. Such exchanges are more useful during the development process than during the deployment phase, when delays in decisions may virtually eliminate all potential benefit of a technology.

To foster public understanding and acceptance of oil spill R&D (including field testing) and of actual usage of the resulting technologies, public acceptability could be identified as an evaluation criterion for projects designed to develop or test new spill response and restoration technologies. The Interagency Coordinating Committee could establish a protocol for assessing the feasibility of using such technologies; this protocol could specify that probable public acceptance be one of the criteria for assessing new technologies. The Interagency Committee also could develop and implement approaches for incorporating public participation in decision making. For example, the public could be involved in developing either standards for technology performance or criteria for the selection of remediation approaches based on habitat type or other factors. Such uses of public participation should be evaluated systematically.

To identify points in the technology development process where public participation would be important, information would be needed about the specific public concerns related to oil spills and their prevention and management. To help develop hypotheses for addressing these issues, it would be useful to review the literature or new case studies on public response, as well as the outcome of public involvement in other environmental arenas.

Coordination with Industrial and Foreign R&D

Assorted oil spill R&D activities are sponsored by industry, states,[23] universities, and foreign organizations in accordance with specific and sometimes unique objectives.

The largest private-sector research program is carried out by the MSRC, which has concentrated on developing and evaluating response technologies such as remote sensing to locate oil, oil/water separation and storage, and countermeasures (e.g., dispersants, bioremediation). A number of oil companies and private oil spill clean-up associations, such as the National Response Corporation and its affiliates, conduct projects related to the safety and integrity of flow systems, oil behavior, mechanical cleanup techniques, separation of oil and water, and waste storage.

In comparison to the overall U.S. effort, less oil spill R&D appears to be conducted in other nations,[24] judging from reports presented during the recent International Oil Spill R&D Forum (USCG/IMO, 1992). Foreign programs vary in size and direction. One of the largest is in Canada, where basic research on the behavior of oil spills addresses such topics as the kinetics of emulsion formation, oil in ice, evaporation, photooxidation, dissolution, sinking, and the long-term fate of oil (Fingas, 1992). Other areas of emphasis include the development of oil spill models, and testing of spill treating agents. As noted earlier, field experiments are common.

Overseas, R&D activities concentrate on response. In Japan, oil pollution is controlled through recovery; specially equipped boats can recover 80 percent[25] of spilled oil, and the remainder is either recovered or dispersed with absorbents, dispersants, or other measures (Kuwabara, 1992). Accordingly, Japan's R&D plan focuses on in-situ burning systems, oil dispersants, development of new technology to combat spills, and an oil drifting prediction program (Kuwabara, 1992). Japan also has a program to evaluate oil booms and oil recovery devices (Tsukino, 1992).

European R&D programs are diverse, due to differences in national response strategies and local sea conditions, but the general emphasis is on response technologies, including support tools for decisionmakers such as manuals and computer models. European nations are at various stages of developing spill behavior prediction capabilities; they all have copies of Seabel, a decision-support system developed in the Netherlands that incorporates a fate and behavior model, and EUROSPILL, a fate and behavior model developed in the United Kingdom (Webb, 1992). France, Norway, and the United Kingdom devote significant effort to chemical countermeasures; some sea trials have been conducted (McDonah, 1992). The French are developing vessels adapted to oil recovery (i.e., with large inboard storage capacity for recovered products), large and reliable floating tanks, and oil water separators that can cope with water in oil emulsion (Peigne, 1992). They also plan offshore tests with skimmers, and, in keeping with a long-term interest in protecting sensitive areas with booms, a manual is being written on the mooring of booms (Peigne, 1992).

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[23] The Texas General Land Office is sponsoring research in oil spill response technology at the University of Texas, the Texas A&M University, Corpus Christi State University, Lamar University, Sam Houston University, and the Texas Technical College. Oil spill response research is sponsored by the California Department of Fish and Game at the University of California at Santa Cruz.

[24] One reason appears to be the widespread perception among European scientists and informed citizens that oil spills, even large ones, are not the catastrophic events they are considered to be in the United States. The European attitude may change as a result of recent major spills near La Corona, Spain (Greek tanker AEGEAN SEA, spilling 22 million gallons of crude oil on December 3, 1992), and off the Shetland Islands (Liberian tanker BRAER carrying 25 million gallons of light crude, most of which spilled; accident occurred January 11, 1993) (Cutter Information Corp., 1992 and 1993).

[25] The committee assumes that this extraordinarily high recovery rate is achieved only under highly favorable operating conditions.

Response R&D in the United Kingdom encompasses remote sensing of oil spill thickness, oil recovery, dispersion, demulsifiers, monitoring of sea birds, shoreline cleanup, and computer modeling (Goodman, 1992). Attention also is turning to detection and management of chemical pollution. Sweden concentrates on developing new response technologies and measures to test those technologies. Among the products developed are a sea-trailer system for transporting response resources from storage sites to accident scenes; a small belt skimmer for work boats, designed for viscous oil in shallow waters; and a special bag for temporary oil storage (Thorell, 1992). Sweden also is developing improved "sweeping" oil booms and methods to detect oil in, under, and on ice (Thorell, 1992).

Some effort has been made to coordinate R&D programs, both within the United States and abroad. For example, the MSRC strives to focus on topics not emphasized by the U.S. government, and it seeks collaborators for expensive studies such as in-situ burning. Environment Canada frequently cooperates on individual projects with the U.S. Minerals Management Service. The Commission on European Communities, through its Advisory Committee on Pollution by Hydrocarbons, provides advice to its members on central research priorities, as well as funds for collaborative research (Webb, 1992). However, as those examples suggest, coordination has been restricted in scope and geography. The effectiveness of these joint efforts has been limited as well. For instance, although cooperation in Western Europe has enhanced national response capabilities, it is reported that the R&D never reached a critical mass to achieve major goals (Barisich, 1992).

Care must be taken to ensure that federal R&D projects do not duplicate unnecessarily the activities underway elsewhere. Some overlap is to be expected and may be useful. A critical review would be required to identify similar efforts, to determine whether duplications were beneficial, and to ensure efficient application of funds by ascertaining whether the results of industrial and foreign R&D programs could be applied to U.S. government efforts. The committee identified a number of R&D areas in which activities seem to coincide. For example, the federal *Oil Pollution Research and Technology Plan* apparently overlaps industry-sponsored activities in areas such as remote sensing and surveillance, and the combined effort in containment and recovery technology may be greater than is economical. Similarly, the combined level of effort devoted to bioremediation may be out of proportion to the limited applications of the technique, which is used primarily for final-stage cleanup or the treatment of lightly oiled shorelines. Some overlap also is apparent in chemical countermeasures, and some U.S. work with dispersants appears to duplicate European studies of the 1970s (National Research Council, 1989). This level of effort may need to be reviewed, particularly in view of the apparently entrenched U.S. position against the use of such chemicals, even for experiments.

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CONCLUSIONS AND RECOMMENDATIONS

The *Oil Pollution Research and Technology Plan* reflects the first coordinated federal R&D effort to prevent, minimize, and clean up oil spills and to restore the environment. The existence of such a plan offers an unprecedented opportunity to make substantial progress in oil spill R&D, an arena that is the focus of considerable public concern and yet has been characterized by sporadic and fragmented advances. To make the most of this opportunity, an assessment is in order to determine what has been accomplished through the planning process, what basis exists for developing a coherent and comprehensive plan, and what steps might be taken to enhance the substance and effectiveness of the federal plan.

ASSESSMENT OF THE FEDERAL PLAN

Accomplishments of the Planning Process

Efforts to accomplish most of the R&D planning and coordination goals of OPA-90 have been initiated and significant progress has been achieved by the Interagency Coordinating Committee.

In the course of the planning process, the Interagency Coordinating Committee has organized and coordinated federal oil spill R&D and has defined the domain of each federal agency involved. A plan has been developed outlining the overall federal approach to this R&D and allocating the dollars authorized by OPA-90. Ongoing R&D projects are being coordinated and co-sponsored by the various agencies. In addition, an international forum has been held to foster collaboration among national governments and industry focusing on oil spill R&D, and a database has been developed to keep track of specific projects worldwide.

The Basis for a Coherent and Comprehensive Plan

Elements that would be desirable in a coherent, comprehensive R&D plan include

(1) an explicit research strategy that is consistent and logical, and that defines broad developmental and operational goals and specific objectives to be met in reaching those goals;
(2) adequate resource allocation, by federal or external sources;
(3) an accountability scheme that assigns responsibilities; and
(4) a rational process for analysis and feedback that permits continual reassessment of the plan, encompassing means for gauging the value (both absolute and relative) of individual projects and the likelihood of accomplishing specific goals and objectives.

To develop such a plan, a methodical, defensible, and scientifically rational approach would be required. Such an approach is systems analysis. An analysis of the oil spill system would determine and evaluate both the problems underlying oil spill issues and the potential solutions. The analysis also would produce a framework identifying intervention strategies to prevent, minimize, and clean up spills as well as the R&D required to support these strategies. The framework could serve as a standard for evaluation and rational evolution of the federal plan.

Enhancing the Substance and Effectiveness of the Plan

The federal plan lacks several important elements of a coherent and comprehensive plan

Although an analysis of the oil spill system has yet to be conducted, a number of conclusions can be drawn regarding the plan based on the facts and a preliminary analysis. The plan is a useful compendium of relevant projects and addresses many important R&D issues, but it lacks several important characteristics of a coherent and comprehensive plan. Absent are an explicit research strategy that is consistent and logical, adequate resources, an accountability scheme, and a rational process for analysis and feedback. Therefore:

> **The committee recommends that the Coast Guard undertake an analysis of the marine oil spill system, which consists of a variety of subsystems beginning with drilling for oil and ending at delivery of the product to the customer. The analysis will lead to an improved understanding of events leading to spills and how actions could affect the cycle of events, particularly those events and their following sequences that damage the environment, and actions that may assist recovery of the environment from such insults. The analysis will provide a basis for maximizing the benefits derived from the federal R&D investment.**

Field testing and demonstration play a vital role in developing oil pollution response technology and in understanding oil behavior in the marine environment

Studies involving experimental releases are the only means of acquiring research-quality data on some response technologies, such as oil dispersants. Laboratory experiments cannot replicate real-world process interactions and variables, and accidental spills provide limited learning opportunities because data on pre-spill conditions and/or spill volume usually are lacking. OPA-90 recognizes the need for field studies, but the federal plan does not emphasize the scientific and technical value of such studies. Therefore:

> **The committee recommends that a program of field testing, as a vital component of an oil spill R&D program, be instituted as part of the federal plan.**

The committee recognizes that, at present, field experiments involving intentional discharges greater than 1,000 gallons effectively are barred in the United States by the lack of well-defined criteria for evaluating the requests. The relevant regulatory authorities should address this issue. The Environmental Protection Agency should establish specific criteria and a review process to allow appropriate field testing so the federal plan can make use of this vital activity.

Issues of public perception are important and must be understood by the relevant agencies

The committee recognizes that public perceptions, especially public reaction to oil spills, are a significant aspect of the overall oil spill problem. Even when these perceptions are not valid scientifically, they are important; public attitudes are, for instance, important factors in determining whether spill response technologies can be used. Therefore:

> **The committee recommends that issues of public perception be addressed in an analysis of the oil spill system and in the federal plan.**

The Interagency Coordinating Committee needs to continue its efforts to sort out overlap and develop more partnerships with industrial and foreign research organizations

Oil spill R&D programs of varying degrees of thoroughness are being carried out under the sponsorship of industrial and foreign organizations as well as states and universities. Some duplication of U.S. government efforts is to be expected and in some cases will be beneficial. The federal plan should accommodate this fact. The Interagency Coordinating Committee has established mechanisms for enhancing cooperation and coordination with industry, foreign research organizations, and universities, and initial discussions have been held to initiate these relationships. But the federal plan has yet to be coordinated systematically with other, parallel R&D efforts. Therefore:

> **The committee recommends that, as part of the federal plan, a critical review be conducted of past and present oil spill R&D carried out worldwide to determine the possible application of results to federal efforts and to avoid unnecessary duplication. The committee also recommends that current efforts to foster communication be continued and expanded.**

The effectiveness of the plan, as further developed based on the committee's recommendations, will depend on investment of adequate resources

To date, the plan consists mainly of a reshuffling of old funding, and indications are that, even if additional funding were allocated in accordance with OPA-90, these resources still would be minimal and would be dissipated among many projects. The short-term funding approach poses a significant barrier to most multi-year research. The plan is unlikely to amount to anything more than a collection of assorted individual agency projects unless adequate funding is provided. Therefore:

> **The committee recommends that the Congress and the Executive Branch invest adequate resources to implement the R&D plan.**

A judgment regarding adequacy of funding should be made by the Interagency Coordinating Committee. Sufficient guidance is provided in the *Oil Pollution Research and Technology Plan* of April 1992 to continue on-going research and to initiate R&D. An analysis of the oil spill system and the resulting evaluation of risk reduction and benefits will enhance the basis for future planning, but this analysis should not delay implementation of the current plan.

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APPENDIX A

BIOGRAPHICAL DATA

COMMITTEE ON OIL SPILL R&D

ROBERT A. FROSCH (NAE) has been vice president of General Motors Corp. and General Motors Research Laboratories since 1982. His experience guiding government research programs includes stints as administrator of the National Aeronautics and Space Administration from 1977 to 1981 and, earlier, as assistant secretary of the U.S. Navy for research and development. He has served as associate director for applied oceanography at Woods Hole Oceanographic Institution and as assistant executive director of the United Nations Environment Programme. Dr. Frosch is a member of the National Academy of Engineering and serves on several of its committees, including the National Academy of Engineering Program Advisory Committee. He received his Ph.D in theoretical physics from Columbia University.

PAUL D. BOEHM is a vice president of Arthur D. Little, Inc. He is the company's director of marine sciences. He is a chemical oceanographer and organic geochemist with particular expertise in marine and coastal monitoring studies and organic pollutant distribution and transport. From 1983 to 1989 he was manager and director of the Marine Chemistry and Geochemistry Section at Battelle, also serving as technical director of Battelle Ocean Sciences for the final two years. He has managed several major oil spill assessments and numerous government and industry research programs. He earned his Ph.D. in chemical oceanography at the University of Rhode Island.

PATRICIA A. BOLTON is a senior research scientist at Battelle Memorial Institute, Environmental Planning and Social Research Center located in Seattle. Since coming to Battelle in 1980, she has carried out research related to hazard awareness, response to warnings, emergency preparedness, disaster recovery, and hazard mitigation. Her research interests extend to both natural and technological hazards and disasters, including public response to dangerous technologies, and federal, state, and local emergency response activities. Her project work at Battelle has included the provision of technical assistance on emergencies for the Nuclear Regulatory Commission and the Department of Energy. She also has special interest in the organizational factors related to maintenance of readiness for emergency response, and the relationship between organizational safety and emergency preparedness. She has served twice as a member of the National Research Council's reconnaissance teams reviewing research needs following foreign disasters. She served as a member of the Washington Seismic Safety Council in 1986 and as the president of the Washington State Sociological Association in 1991. Dr. Bolton received her B.A. from the University of New Mexico and her Ph.D. in sociology from the University of Colorado.

RICHARD T. CARSON, JR. is an associate professor of economics at the University of California, San Diego, where he has been a member of the faculty since 1985. His areas of specialty include natural resource economics and econometrics. Dr. Carson was formerly a staff member for Resources for the Future, a non-profit research organization. He has assessed the benefits and costs associated with changes in environmental amenities for a number of government agencies and most recently was a principal investigator for the State of Alaska on the damage assessment for the EXXON VALDEZ oil spill. Dr. Carson has written or co-authored dozens of journal articles, books, and reports. He received his Ph.D. in resource economics from the University of California, Berkeley.

PHILIP M. DIAMOND is principal director, Special Applications Office, for The Aerospace Corp., a federally funded research and development center supplying design and engineering support to the Department of Defense. His responsibilities include providing technical support to the U.S. Navy. His areas of technical expertise include environmental and oceanographic sensors, general systems engineering and analysis, and systems integration. He has worked with oceanographic and naval sensing and communications as well as with environmental sensing systems and is credited with a number of systems innovations. Dr. Diamond has held a wide range of technical and management positions with The Aerospace Corp. since 1961. He earned his Ph.D. in mechanical engineering at Purdue University.

STUART A. HORN is manager of spills and crisis preparedness for Mobil Oil Corp. He began his career with Mobil in 1956 and has managed the company's oil spill training programs, research, and response capabilities worldwide since 1972. He also coordinates Mobil Foundation grants to institutions engaged in oil spill research. Mr. Horn has served as chairman of various American Petroleum Institute (API) committees and task forces focusing on oil spill research. He was the technical adviser to the API study group that developed the U.S. oil industry proposal for the Petroleum Industry Response Organization (PIRO), now the Marine Spill Response Corporation. His international experience includes work with the International Petroleum Industry Environmental Conservation Association (IPIECA) since its inception. Mr. Horn received his B.S. in chemical engineering from Pennsylvania State University.

JOSEPH A. NICHOLS has been technical manager for the International Tanker Owners Pollution Federation Ltd. since 1987. He was assistant technical manager for the preceding nine years. Prior to that, he was senior scientific officer for Warren Spring Laboratory, Department of Industry, United Kingdom, where he studied the behavior and fate of oil and chemical pollution at sea and developed materials to combat spills. Mr. Nichols has provided technical advice at some 70 oil spills, and his contributions include the development of aerial application techniques for oil dispersants. Mr. Nichols received his B.S. in chemistry with honors from Brunel University, England.

EDWARD H. OWENS is vice president and senior consultant for Woodward-Clyde Consultants. He has been involved in studies related to the environmental impact of oil spills and spill cleanup operations since 1970. He advised cleanup operations following a number of major tanker spills and has undertaken field studies on the impact and persistence of stranded oil at sites around the world. He pioneered the use of aerial videotape surveys for shore-zone mapping, coastal inventories, and oil spill countermeasures. Dr. Owens has conducted foreign missions to Africa, South America, and the Caribbean on behalf of the International Maritime Organization (IMO) and has published more than 100 scientific papers and reports. His previous assignments have included other management positions with Woodward-Clyde and research posts with the Canadian government. He earned his Ph.D. in geology at the University of South Carolina.

ROBERT T. PAINE (NAS) is a professor of zoology at the University of Washington, where he has been a member of the faculty since 1962. He is internationally recognized for his contributions in ecology, including marine ecology. His many publications include a classic paper on food web complexity and species diversity. His honors in the United States and abroad include election to the NAS in 1986, the MacArthur Award from the Ecological Society of America in 1983, and Germany's Ecology Institute Prize in 1989. He received his Ph.D. from the University of Michigan.

MALCOLM L. SPAULDING is a professor and chair of ocean engineering at the University of Rhode Island, where he has been a member of the faculty since 1973. He specializes in numerical modeling of nearshore and coastal processes, including hydrodynamics, oil and pollutant transport and fate, waves, and sediment transport. In 1979 he founded Applied Science Associates, Inc., to provide engineering and marine science services for government and private clients. He has managed numerous government research programs and has many publications and honors to his credit. Dr. Spaulding received his Ph.D. in mechanical engineering and applied mechanics from the University of Rhode Island.

JOHN M. TEAL is a senior scientist at Woods Hole Oceanographic Institution, where he has been a member of the research staff since 1961. His research interests include coastal marine ecology and petroleum pollution and hydrocarbon biogeochemistry. He is a recent chairman of the Scientific Advisory Committee of the U.S. Minerals Management Service Outer Continental Shelf Program. He has written or co-authored more than 125 papers, articles, and books and has participated in numerous workshops and studies at the international, federal, and local levels, including oil spill workshops sponsored by the U.S. Office of Technology Assessment. Dr. Teal received his Ph.D. from Harvard University.

APPENDIX B

Pipeline and Platform Oil Spills 50 Barrels or Greater on the Outer Continental Shelf Sectors of U.S. Marine Waters

	PIPELINE SPILLS*		PLATFORM SPILLS*	
Year	Number	Volume	Number	Volume
1964	0	0	5	14,528
1965	0	0	2	2,188
1966	0	0	0	0
1967	2	160,703	0	0
1968	1	6,000	1	85
1969	5	8,937	6	82,950
1970	1	50	6	83,773
1971	2	150	9	1,160
1972	1	100	0	0
1973	1	5,000	4	17,269
1974	3	23 ,398	5	575
1975	0	0	2	266
1976	2	4,414	1	300
1977	3	600	1	70
1978	2	1,035	1	104
1979	1	50	4	2,045
1980	1	100	8	2,481
1981	2	5,180	4	382
1982	0	0	3	842
1983	2	205	7	1,734
1984	0	0	2	150
1985	2	370	6	984
1986	2	329	1	52
1987	0	0	1	60
1988	1	15,576	3	222
1989	0	0	1	300
1990	2	18,992	1	110
Total	36	251,189	84	212,630

Source: Minerals Management Service, U.S. Department of the Interior (Data provided to the committee September 21, 1992)

APPENDIX C

METHODOLOGY FOR ANALYZING THE OIL SPILL SYSTEM

Defining the System

The analysis would examine the oil spill system as a whole, including the various relevant subsystems such as oil transportation (by water), spill evolution, spill response, and public response. The system must be defined carefully. The model must be comprehensive enough to capture the true behavior of the system, but not so overextended as to become unwieldy and impossible to analyze.

The spill system model provides the analytical tool to determine where and how spills occur in the system, and what the consequences are. With this information, the appropriate type(s) of intervention can be selected. The type of intervention is a function of spill characteristics, such as volume, frequency, ecological and property damage, and location.

The most obvious elements of the system include the oil production, transport, handling, processing, and distribution infrastructure, and the issues and systems associated with the consequences of a spill.[26] The components include source-associated gear (e.g., drilling equipment, pumps, storage tanks, and pipelines), transport-associated gear (e.g., tank vessels, pipelines, and peripheral equipment), refinery-associated elements (e.g., processing facilities, pipelines, storage tanks, and peripheral equipment), and transfer and distribution machinery incorporating many of the aforementioned types of equipment. The "soft" aspects of the infrastructure include personnel, management and procedures, training, traffic management and control, vessel navigation, and technical design, manufacture, and operations.

Other subsystems may be more difficult to characterize. It is far more straightforward to model the transport subsystem than, for example, to model spill events and evolution. The latter task is more difficult due to the far larger number of variables associated with spills, and the greater uncertainty surrounding many of those variables (which include weather and sea state, nature of the coastal and beach condition, type of ecosystem, and effects on the ecosystem). This subsystem cannot be ignored, however, or the spill system model would not be comprehensive and would ignore response and restoration R&D.

Refining the Model

In developing and augmenting the initial model of the spill system, a variety of analytic questions would be addressed, such as:

- Does the model(s) represent current and anticipated reality accurately enough to produce useful and appropriate results?
- What are the experiential incident statistics that support the development of a model(s) and can

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[26] It might be argued that this is not a formal system, but rather a quasi-random and arbitrary grouping of elements, processes, and activities, and that, consequently, little would be gained by a systems analysis. However, this argument is merely semantic. The elements, processes, and activities clearly are linked, are interdependent, serve a common purpose, and can be circumscribed by a boundary penetrated by input and output. These are the characteristics of a system.

these be used to verify the model(s)?

- What technological, procedural, training, and other factors can be identified to ensure that the model(s) is applicable to the future?
- Are nodes in the model, based on available statistics, identifiable as key factors in the process such that attention to the related problems would reduce significantly overall spillage?
- What are the statistical distributions of spillage (e.g., large versus small spills) and what are the implications for risk analysis, consequences of spillage, and corrective measures?
- What spills cause the most damage (characterize by oil type, location of spill, and environment affecting spill progression or change) and how should these spills be managed (intervention form, prevention, response, resolution)?
- What implications for an R&D strategy and an investment strategy can be drawn from the results of statistical and modeling/simulation analysis?
- What implications can be drawn regarding the effectiveness of existing spill prevention and response technology and procedures?
- What functional linkages exist among the root causes of system failure, proximate causes of incidents, the nature of the regulatory process and emergency decision process, the remedies utilized, the perceptions of the public (both local and remote), and the reactions of industrial, legal, administrative, and legislative communities?

A Step-by-Step Guide

Any of a number of different methods could be used to establish a coherent R&D plan. Following is a procedure the committee judges to be appropriate, reasonable, and likely to lead to the desired result. The process is broken down into four phases: statement of the problem, analysis, alternatives and reformulations, and synthesis. A total of 14 steps are involved.

Statement of the Problem

1. Assume a general schema that treats oil spills as the results of component failures in the oil spill system or process. The system should be interpreted to include the factors governing execution of the process, such as regulatory provisions and personnel training. It also should include modeling of spill properties and the strategies and tactics of spill response.

2. Establish a representative model(s) of the real oil spill system.

3. Within the model, identify functions for each segment of the process ("functional modality") set off by nodes representing significant changes in oil handling activities, the environment, or other realities. Three examples of functional modality are those periods when an oil tanker is connecting to, discharging to, and disconnecting from a land-based pipeline network. Examples of functional modalities associated with spillage are the initial spill period prior to the time when winds, currents, and oil flow dynamics push the spill to large and uncontrollable areas; the period when spills reach beaches or harbor facilities; and the period of cleanup and restoration of a coastal region.

4. Identify and causally connect, for each of the functional modalities, the relevant details concerning the spill system. The particulars may include the type of oil being transported, ship crew training, ship design and safety equipment, navigation systems, the sea environment and proximity to shore, beach and ecosystem sensitivity, the parameters of pipelines or barges, or values of ecosystem population elements.

Analysis

5. Based on experience as well as available statistics, analyze the model to determine, for each functional modality, where risk points exist, the consequences of events, branch points for the normal and abnormal progress of the process, and points where regulatory, supervisory, legal, public, and industrial entities intersect the system. For example, oil transport in the open ocean may be significantly less hazardous (and a lesser concern) than the voyage phase near shore; or, small releases in harbor areas due to incidental operations ("industrial accidents") may prove to be very significant and yet to receive little public and government attention because of their routine nature.

6. Evaluate the results of step 5 to determine the frequency and seriousness (i.e., economic and environmental damage) and the impact on public perception of the possible events and, therefore, the relative and absolute importance of the possible events in terms of a "Figure of Merit (FoM), which may be assigned a dollar measure. In determining an FoM (particularly if it is expressed in dollars) the systems analysts will have to exercise particular care to avoid the pitfalls involved in capturing variables stemming from non-economic or ethical issues. These judgments may be applied after construction of the system model and its analysis.

7. For each of the significant possibilities identified in step 6, determine existing and/or speculative measures that might prevent, eliminate, or mitigate the consequences of the event and restore the environment. For each measure, gauge the value, cost, or impact on the FoM. For example: It may be more cost effective and faster to improve crew training than to convert the tanker fleet to double hulls; utilizing surface combustion of a floating oil spill may be more effective, overall, than collecting and disposing of the oil; or "doing nothing" may be more effective than steam-cleaning a beach.

8. For cases where a significant spill is possible, model and evaluate the nature of the spill and its environment, the impact on the environment, and means for mitigation and restoration. (This step, which relates to development of response techniques and devices, requires much thought and is well suited to a scientific approach aimed at reducing the physical and chemical uncertainties associated with technology development. Research into ecosystem effects and response phenomena, based upon improved understanding of natural processes, would support the analysis.

9. Perform an assessment of these alternative measures, considering their cost, feasibility, technological or other risk/uncertainty, development period and implementation schedule, and social impact.

Alternatives and Reformulations

10. Using the results of step 9, re-examine the model generated in steps 2 and 8 to identify system or process alternatives (paradigm changes) that could eliminate or reduce risk and balance the consequences against cost, social impact, and issues of public perception. An example of such a change might be the introduction of a vessel traffic control system.

11. For the model generated in step 10, repeat the analysis described in steps 5 through 9.

Synthesis

12. By iteratively combining the results of the modeling and analysis, establish an R&D framework or roadmap that includes specific goals and objectives for each of the relevant measures.

13. Through development planning, establish for the completed framework a series of research, development, and acquisition strategies, and plans for the achievement of the individual goals.

14. Combine the results into a single, coherent plan in which the goals and objectives are correlated directly with the problems and issues identified in step 6 and with overall goals represented by the final "objective" model developed in step 10. Categorize projects into basic and applied research, development and demonstration, engineering development, and engineering or operational implementation.