The MIT/Marine Industry Collegium
Opportunity Brief #35

Case Studies of the MIT Oil Spill Model

A Project of
The Sea Grant College Program
Massachusetts Institute of Technology
MITSG 84-2

The MIT Marine Industry Collegium

CASE STUDIES OF THE MIT OIL SPILL MODEL

Opportunity Brief #35

Revised Edition
June 30, 1984

Marine Industry Advisory Services
MIT Sea Grant Program

Cambridge, Massachusetts 02139

Report No. MITSG-84-2
Grant No. NA81AA-D-00069
Project No. A/M-2

Preface

This Opportunity Brief reports on a workshop entitled, "Case Studies of the MIT Oil Spill Model." The workshop was sponsored by the MIT Sea Grant Marine Industry Collegium, which is supported by the NOAA Office of Sea Grant, by MIT and by more than 100 corporate and government members. The workshop was held to provide Collegium members an opportunity to discuss the details of the Oil Spill Model that was developed at MIT and to learn about the model's application to three different cases. The workshop agenda is provided in the appendix.

The Oil Spill Model work began in 1978 with a suggestion from industry that MIT researchers, J.D. Nyhart and H.N. Psaraftis, develop a model that would be useful to policy makers as a strategic tool for responding to accidental spills. The model was additionally designed to serve as a tactical tool for studying optimal response to oil spills in a cost-effective and politically acceptable way.

The opinions and conclusions presented herein are those of the author(s) and do not necessarily reflect the views of the MIT Sea Grant College Program or of MIT.

Through Opportunity Briefs, workshops and other interaction, the Collegium provides a means for technology transfer among academia, industry and government for mutual benefit. For additional information about the Collegium or about the research presented, contact the Marine Industry Collegium, MIT Sea Grant Program, 292 Main Street, Cambridge, Massachusetts 02139 or call (617) 253-4434/7092.

Margaret Linskey
June 30, 1984

TABLE OF CONTENTS

		Page
1.0	Business Perspective	1
2.0	Introduction	2
3.0	Description of the Model	6
3.1	Sub models	6
3.2	Limitations of the Damage Assessment Model	9
4.0	Applications of the MIT Oil Spill Model	11
4.1	The Argo Merchant Case	11
4.2	The Petro-Canada Case	13
4.3	Port of Charleston Case	14
4.4	Potential Use of the MIT Oil Spill Model by the U.S. Coast Guard	15
5.0	A Discussion of the Valuation of Natural Resources	17
6.0	Summary	22
7.0	Related Reading	23
8.0	Appendix	26

1.0 BUSINESS PERSPECTIVE

Over 9.8 million gallons of oil were accidently spilled by tanker ships on U.S. waters in 1977. Over 11.6 million gallons were spilled in all kinds of accidents combined. An estimated additional 30 million gallons of oil pollution occurred through operational discharges of ballast, bilges and other oily water from ships.

Accidental spillage was distributed with 18% on inland waters, 27% on coastal waters less than three miles from shore, and the balance of 55% on waters three miles or further from shore which would have required a high seas cleanup capability for removal.

By geographical coastal area, the offshore accidental spillage was distributed with 11% in the Atlantic, 18% in the Gulf of Mexico and 71% in Pacific waters.

The oil industry has paid over $100,000,000 in costs for cleaning up approximately 60 major oil spills occurring worldwide since 1967. In the United States, the Coast Guard alone spent over $20,000,000 in cleaning up 39 incidents from 1970 to 1976. Of these 39 cases, less than $800,000 has been reimbursed by industry, due to confusion in the interpretation of the governing liability laws. Because of the existing legal complexities in forcing compensation for damages from the spiller, many observers speculate that the $100,000,000 which has been paid by industry actually represents but a small fraction of the total damages arising from the 60 spills.

As stated in an earlier Opportunity Brief on this topic "A need still exists to provide and maintain a national capability to clean up accidental spills. Without an offshore cleanup capability, the United States will face expensive rehabilitation of critical environmental areas following oil spillage offshore. Without such a capability, there exists no opportunity to reduce the immediate and overall deleterious effects of oil pollution."

Measures for preventing oil spills hold some hope for controlling the problem in the future. However, human error lies outside the control of the most effective rules and regulations. Oil will continue to be spilled.

The cleanup problem is compounded by questions of who is responsible and who is liable, who should bear the cleanup costs and how much should be spent, what are the costs to society of environmental damage compared to the costs of cleanup. Oil spill cleanup is, in fact, a problem in systems analysis that requires an integrated solution involving legal, technical and economic issues.

2.0 INTRODUCTION

In 1978, an MIT/Marine Industry Collegium workshop first addressed the need for research into accidental oil spills. One of the Collegium members at that meeting was the president of JBF Scientific, a company that manufactures skimming equipment for oil spill cleanup. He pointed out that the small-to-moderate spills which occur during normal operations of shipping and coastal industries need to be considered as well as large ship-load spills. He offered to share his experience and business perspective with MIT researchers in a systematic quantitative study of the spill problem and alternative responses to the spill.

A project proposal was submitted to the National Sea Grant College Program by Professor J.D. Nyhart of the MIT Sloan School of Management and Department of Ocean Engineering, and Professor H. Psaraftis, also of the Department of Ocean Engineering. The multidisciplinary system analysis and modeling proposal was funded by Sea Grant for two years beginning July 1979.

The objectives of the original research project were to create a model that would be useful to policymakers as a strategic tool for responding to accidental oil spills under varying assumptions and conditions. In addition, the model was designed to serve as a tactical tool for studying optimal courses of action to combat oil spill pollution in a cost-effective and politically acceptable way.

A research team was assembled, consisting of MIT researchers, the corporate president whose suggestion triggered the project, another local corporate president, a biologist, and six students. Later a consulting firm from California with experience in environmental damage assessment was added to the team to develop a damage assessment sub-model and to link it to other component sub-models. The work of this firm, and of other damage assessment team members, was supported by a grant from another office of NOAA.

The research team formed an advisory committee comprised of individuals from oil companies, environmental groups, governmental agencies, and equipment manufacturers, including: representatives of the Coast Guard, the Navy, the Massachusetts Office of Environmental Affairs, the Spill Control Association of America, JBF Scientific Corporation, Texaco, Atlantic Richfield, the Oil Spill Intelligence Report, the National Office of Coastal Zone Management, the Sierra Club and the New England Legislative Caucus. In addition, contacts were initiated with various other organizations interested in the project, such as Shell Oil Company, BP England, BP North America, Shell International Labs (Amsterdam), the Intergovernmental Maritime Consultative Organization (IMCO), and the International Tanker Owners' Pollution Federation in London.

This Opportunity Brief reports on an MIT Marine Industry Collegium workshop held on October 13, 1983 entitled,"Case Studies of the MIT Oil Spill Model." The workshop was attended by 57 people from industry, government and universities. This report is a follow-up to Opportunity Brief #25, "Oil Spill Clean-Up: An Economic and Regulatory Model," July 1, 1981.

One of the Principal Investigators on the MIT Oil Spill Model project, Professor J.D. Nyhart of the Sloan School of Management, presented the legal sub-model as well as parts of the different case studies at the October 13, 1983 workshop. The other Principal Investigator, Professor H. Psaraftis of the MIT Ocean Engineering Department, presented the Canadian and Port of Charleston cases. Representatives from the U.S. Navy Facilities Engineering Command and the Coast Guard discussed their role in using and implementing the model, and finally, an economist from the NOAA Ocean Assessment Division discussed methods for attaching monetary value to damage to the marine environment incurred by oil spills.

Three applications of the MIT oil spill model were discussed in detail. The model has been used to examine the 1976 Argo Merchant oil spill from a standpoint of what actually happened and from an assumed worst case analysis. In the latter, the inputs to the computer were changed to simulate what would have happened had the environmental circumstances been much more unfavorable. The Argo Merchant analysis demonstrates the value of the model to play "what if" games for the purpose of tactical planning. Another application has been for a Canadian petroleum company concerned about possible environmental consequences of offshore oil spills, and where best to strategically stockpile chemical dispersants. The U.S. Navy Facilities Engineering Command in Charleston, South Carolina is using the model in both its strategic and tactical modes to analyze potential oil spill problems in the Port of Charleston.

On the basis of these initial evaluations, the MIT Oil Spill project has significantly enhanced the state-of-the-art in modeling oil spill cleanup operations. This model can result in significant savings to the users because it weighs all facets of a problem and integrates the information in a way that enables managers to decide the best course of action both at the time of a spill and in planning contexts. The following reasons support this assertion.

1) This model work has synthesized the most important aspects of this complex problem (such as technical, economic, managerial and regulatory questions) into an integrated analysis.

2) The study has produced innovative decision algorithms that can assist the decision-maker (either at the planning or at the operational level) in allocating cleanup resources in an optimal way.

3) The strategic/tactical/operational decision algorithms are significant theoretical accomplishments from an operations research or mathematical programming point of view.

4) The study's generic approach to damage assessment can be used to quantify the damage consequences of a wide range of oil spill scenarios in a region, without waiting for those scenarios to actually occur.

5) Significant insights (some of them counter-intuitive) can be obtained by running the model against simulated scenarios. The "what if" capability of the model is perhaps its most significant asset as a tool to analyze cleanup alternatives. Significant savings in equipment acquisition can be made based on running a worst case scenario.

Research Update

Research during the past academic year focused primarily on the reformulation and development of the Damage Assessment Model. A masters thesis by Dimitrios Demis included a new formulation for the economic consequences of oil spill damages, based in large part on the general formulations made by the National Oceanic and Atmospheric Administration and others in the Amoco Cadiz case. (The Amoco Cadiz was a petroleum tanker which spilled an immense amount of oil over the French coast in 1978.) Demis further examined issues involving long-term logistical planning, focusing on the differences between small and large spills.

According to the recent thesis, there are two major differences between "large" (over 50,000 gallons) and "small" (up to 50,000 gallons) oil spills. First, small spills are much more frequent. Second, and perhaps surprisingly, small spills exhibit a significantly higher damage potential (anticipated damage cost per unit volume) than large spills. These differences have significant implications on the response strategies that should be used to combat the two types.

The implications range from the expected result that equipment to combat small spills should be geographically distributed, whereas capability to respond to large spills should be consolidated at one or a few large-scale regional response centers, to some other less expected results. Such results refer to issues regarding the generic type of cleanup technologies that should be recommended for either category of spill, to the cost-effectiveness of cleanup in both cases, and to some other more subtle issues.

Finally, a new proposal has been developed to continue work under the auspices of the U.S. Navy Facilities Engineering Command, furthering the development of the model and its application to that group's contingency planning.

Currently, the MIT research team plans to structure the computer programs in a "generic" form, as well as standardize the data collection procedures that would be necessary for any regional applications of the model in the future. Close contact with regional oil spill managers is imperative to the model's effectiveness.

3.0 DESCRIPTION OF THE MODEL

Much of the information in this section is based on a paper that was presented at the February 28 - March 3, 1983 Oil Spill Conference in San Antonio, Texas and has since been published in the proceedings of that conference, entitled First Experiences of the MIT Oil Spill Model, written by J.D. Nyhart and H.N. Psaraftis.

Figure 1 shows the structure of the model and the linkages of its three basic elements: inputs, submodels and outputs.

- Inputs to the model are essentially data bases that have been developed to provide the decision maker with all the available information to evaluate a decision.

- Submodels, also called models, are computer algorithms where all calculations, assessments, and tradeoffs are performed.

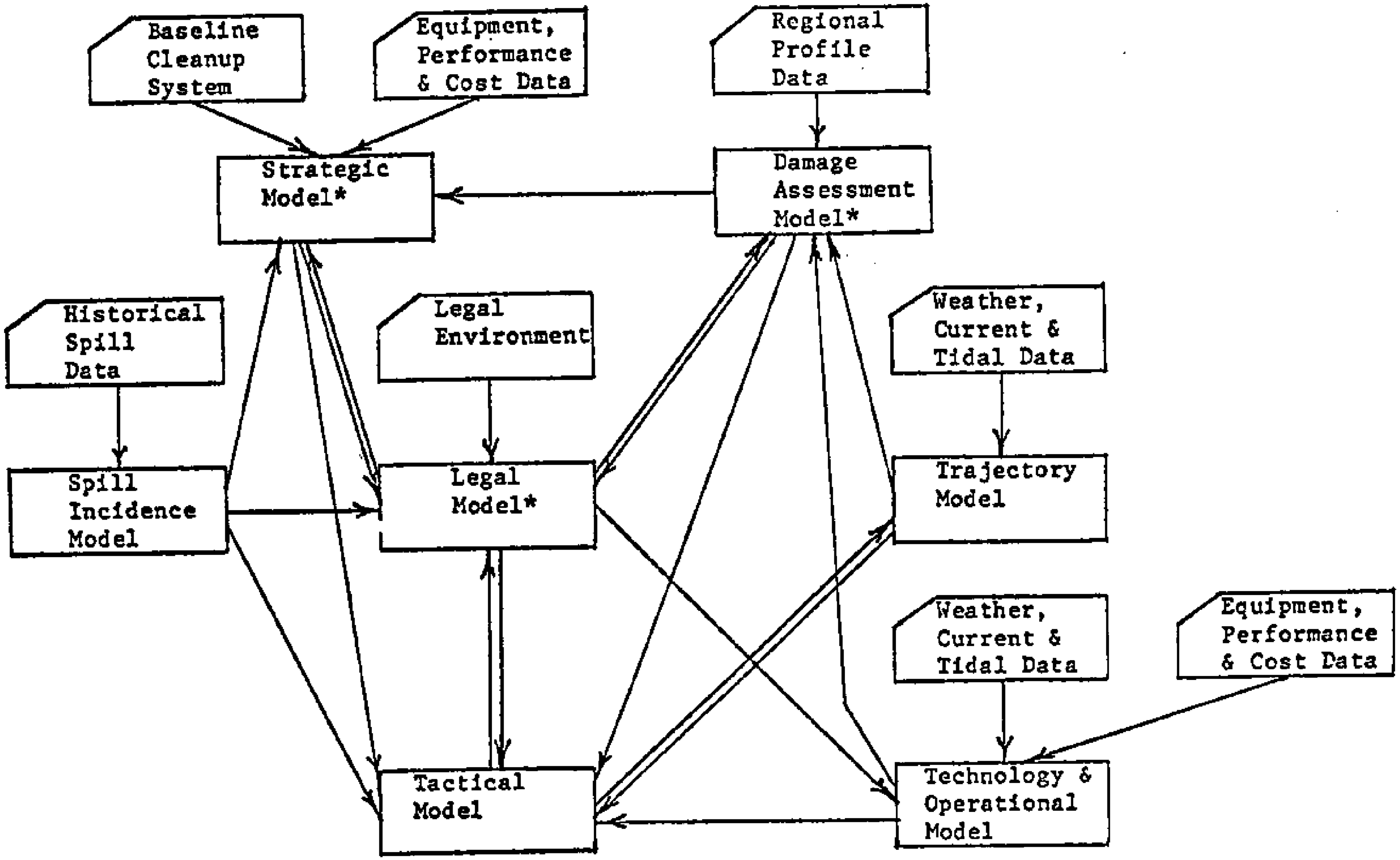
- Outputs of the model are decisions, recommendations and other issues relevant to the specific problem addressed.

The overall model consists of a number of submodels which are described below. An important feature of the overall model is the modular design which allows revision of individual submodels without requiring modification of other parts of the overall model. The computer code is written in FORTRAN-IV and is implemented in an interactive mode on a VAX 780/11 computer at MIT.

3.1 Sub models

The Spill Incidence Model is the "generator" of oil spills. These spills are simulated according to probability distributions concerning their volume, frequency of occurrence and geographical location. Such probability distributions can be derived using several methods from the Historical Spill Data part of the input. The Strategic Model evaluates planning decisions in response to oil spills that may occur in the future and for a given geographical area.

These strategic decisions involve issues such as locations, quantities and types of potential oil spills that may occur over a specified period of time. The objective function is to minimize the expected total costs from oil spills over the period of consideration, costs which consist of fixed investment costs, spill specific cleanup costs and damage costs. Inputs for the Strategic Model come from the Spill Incidence Model (spill probabilities), from the Equipment Performance and Cost Data parts of the input, and from the Damage Assessment Model. Part of the input describes the current system for responding to oil spills, against which any system proposed by the strategic model can be compared.



* Principal Outputs:

- strategic decisions
- tactical and operational decisions (see text)
- evaluation of damages
- policy and regulatory issues

Figure 1

The Tactical Model addresses decisions to be made upon the occurrence of a specific spill. For instance, decisions can be made on the aggregate level of oil recovery capability (i.e., gallons of oil recovered per hour) that is necessary to control the spill to some desired level. Another aspect of the Tactical Model is to determine how the level of oil recovery reliability should be dynamically adjusted in time throughout the duration of the spill, due to changes in outflow rate and weather conditions (Weather, Current and Tidal Data part of the input). In addition, the Tactical Model is linked with the Operational Model to determine what specific sets of cleanup equipment (booms, skimmers, dispersants, etc.) should be dispatched to the spill site, chosen from the stockpile of such equipment located in the vicinity of the spill. The latter model provides more detail on actions that should be undertaken at the spill site, while considering issues such as efficiency and geometric characteristics of booms and skimmers, performance of specific equipment in bad weather, efficiency of dispersant application as well as the relevant costs of cleanup.

Critical tactical and operational decisions depend on what happens, or may happen to the oil once it enters the marine environment and vice versa. Two components of the overall model are linked with the Tactical Model for that purpose: the Trajectory Model and the Damage Assessment Model.

The Trajectory Model tracks the movement and spreading of the oil on the sea surface. Numerous processes act on the oil once it is discharged into the water: evaporation, natural dispersion, drift, emulsification, biodegradation, photooxidation and sedimentation are the most important. Each of those depends on the type of oil as well as the general environmental conditions (Weather, Current and Tidal Data). The MIT team reviewed all existing trajectory/transport models and finally decided to develop its own, so as to better integrate it with the rest of the model. The Trajectory Model is a state-of-the-art model, which includes features such as effect of water depth on oil slicks and breaking up of large slicks.

The Damage Assessment Model takes into account the movement of the oil furnished by the Trajectory Model and evaluates damages to resources impacted as the oil moves through offshore and coastal areas. The Resources and Other Regional Profile Data part of the input is a region-specific inventory of environmentally and economically sensitive resources, tabulated in a rectangular grid format. This submodel evaluates potential damages to marine fisheries, organisms, plants, tourism and other categories. It is linked to both the Tactical and the Strategic Models.

Finally, there is the Legal Model. An oil spill and its cleanup can be viewed as occurring within a legal environment separable into categories including legal aspects of planning, response action, environmental protection, liability and compensation. Each may provide enabling rules and constraints which affect the delegation of authority and responsibility to a range of actors. These include the spiller, terminal/facility owner, local emergency cleanup personnel, the Coast Guard, other government officers, volunteers, cleanup contractors, equipment manufacturers, and those damaged by the spill.

Given claims for damages by numerous parties such as property owners, the tourist industry, fishermen and recreational users, the Legal Model is designed to analyze how the liability is represented in these claims transferred by the action of the legal regimes for liability and compensation to other, ultimate bearers of the cost. As it takes input from the Damage Assessment Model, the Legal Model eventually identifies a number of claims or estimates of damages in various categories. Then it evaluates these claims in terms of a library of statutes--the Federal Water Pollution Control Act, general maritime law, state acts, and international conventions -- to see and compare how these different acts compensate the original bearers of the loss, leave them without compensation or otherwise force the spiller to bear the cost. The federal taxpayer (i.e. the federal government); the state taxpayer (i.e. the state government through its compensation funds and so on); the oil industry and its customers (assuming that many of the compensation and cleanup costs are passed on in the form of higher prices); and the original bearers end up with the ultimate burden of the oil spill.

3.2 Limitations of the Damage Assessment Model

According to the Demis masters thesis cited earlier, the existing Damage Assessment Model represents a first effort to build a comprehensive model of the potential damages from oil pollution in the marine environment, using both qualitative and quantitative results from spill case studies and from laboratory research. The model breaks down the damages due to spilled oil into several categories and subcategories. Then it uses the collected data about the marine resources in the examined area and statistical data obtained by the oil spill case studies to calculate the losses associated with each category. The sum of these losses represents the damages caused by the oil spilled during each time stage. Although the model tries to include as many categories of damage as possible, the data necessary for the operation of the algorithms are very difficult to find.

There are important limitations to the existing model which, according to Demis, can be improved by the following suggestions.

The first limitation of the Damage Assessment Model concerns the structure of the computer program that calculates the oil spill damages. Although everybody accepts that generality must be one of the main virtues of the model, the initial program was developed for the New

England area. The Charleston application has shown that transferring the model to other geographical areas requires extensive modifications before being used. As a result, the overall model has proven cumbersome, as additional effort, time and expense are needed each time it is applied to a new area of interest. One of the goals of the Demis research is to develop a new, much more generic Damage Assessment Model. The associated computer subroutines will be built in such a way that the user will be able to run the program for any geographical area without interfering with its structure. He will only have to change the inputs that describe the marine resources in the area under consideration.

The second limitation is related to the formulation of certain algorithms and the issue of double counting. The existing model is separated into many categories and subcategories, and it is not always clear that the economic effects of a particular spill are properly contained in only one category. This problem is obvious in the damage categories related to recreational and tourist losses. To overcome the problem, a new methodology inspired by the NOAA study of the Amoco Cadiz case was developed. The result is a new unified damage category which includes all the economic losses to people whose recreational opportunities will be harmed because of oil spill pollution.

A third weakness of the Damage Assessment Model concerns the very complicated issue of mortality of fish and other living organisms caused by exposure to petroleum products. Unacceptable uncertainty clouds both the concept of mortality and the assumptions behind the mortality functions used. Moreover, the estimate of the duration of the impact between fish and oil has been ignored. This time parameter is probably the most important factor for the assessment of fish mortality from oil, and neglecting it can seriously reduce the reliability of the model's results. In addition, an improper definition of this time parameter may be in contrast to the summation of damages through time and may cause erroneous results from the Tactical Model. It is proposed that new work be undertaken focusing on these areas.

4.0 APPLICATIONS OF THE MIT OIL SPILL MODEL

4.1 The Argo Merchant Case

The model has been used to investigate actions, events, costs and damages associated with the Argo Merchant oil spill, which occurred off the coast of Massachusetts in December 1976. That spill was chosen because it allowed the investigators to run the model with well documented input data. The incident also provided an opportunity to address some important speculations such as, "What would have happened if winds in the Argo Merchant oil spill had been blowing in the opposite direction?" or, "What if the spill had occurred in the midst of the summer tourist season and winds carried it on the New England coast?" Such questions were analyzed from the point of view of oil spill trajectory, equipment dispatching, cleanup costs and damage assessment.

Data bases for the Argo Merchant spill were developed using the following information:

- Oil outflow and weather conditions.
- All major equipment mobilized during the incident (this database was broken into four cleanup techniques: offloading, mechanical removal with and without storage, and chemical dispersants).
- Performance and cost data of the equipment based on best estimates from experimental results, manufacturer specifications, and contractor data sheets.
- Dispatching time estimates for each of the sets to arrive on the site.
- Damage assessment data, based on information available on fisheries, tourism, property values, and value of lost oil.

Offloading was assumed feasible throughout the event despite bad weather conditions.

Outputs of the computer runs for the Argo Merchant case included reports describing the slick status through time (updated at 6-hour intervals), as well as the status of equipment deployment. Output variables included volume of oil, volume of oil-water emulsions, slick thickness, slick surface area, volume of oil offloaded, mechanically removed and dispersed, damages caused by escaping oil and cleanup cost incurred, as well as how all of those changed through time. In addition, the program indicated which specific equipment sets constituted the response through time.

Two main categories of test runs were estimated: runs related to the actual incident, and runs based on an assumed worst-case scenario.

The worst-case variant differed from the actual case in three respects. First, wind direction was shifted by 190 (clockwise), so that the spill could move toward the Massachusetts coast. Second, occurrence of the incident was changed from winter to summer, at the height of the tourist season. And third, oil was assumed to be light Diesel No. 2 instead of crude, so that its toxicity would cause more damage.

For both actual and worst-case scenarios, two kinds of spill response were investigated: the "do-nothing" response, in which the model was forced to neglect the spill (a politically unlikely, but not completely impossible option), and the "optimal" response, in which the model recommended the response that minimized the sum of cleanup plus damage costs. Any combination of cleanup techniques was allowed. Table 1 summarizes cleanup and damage costs for the four runs.

Table 1

Summary of cleanup and damage costs for four scenarios (two actual and two hypothetical) of the Argo Merchant spill, as recommended by the Tactical/Operational Models.

	"Actual" Scenario		"Worst-Case" Scenario	
	Do-Nothing	Optimal	Do-Nothing	Optimal
Cleanup Cost	-	$0.086M	-	$0.034M
Damage Cost	$4.6M	$0.79M	$34.8M	$1.1M
Total Cost	$4.6M	$0.876M	$34.8M	$1.134M

The value of these and subsequent runs does not rely so much on the actual numerical values of the outputs, but on the insights that can be obtained and the patterns that can be identified by studying those outputs in detail.

1. As expected, damage costs for the worst case scenario were much higher than those for the actual scenario. Actually, in the worst case most of the damage was inflicted on natural or economic resources, while in the actual case most of the damage was the value of the lost oil.

2. In both cases, there was a drastic damage cost reduction if the do-nothing response were replaced by the optimal response recommended by the model. In both cases the technique that was given priority was offloading.

3. The surprisingly lower cleanup cost of the worst case scenario can be attributed to the significant increase in the operational efficiency of the offloading equipment for Diesel Oil No. 2 in comparison to that for crude oil, due to much lower viscosity. Under such circumstances, no extensive mobilization of such equipment was necessary.

4.2 The Petro-Canada Case

Another important application of the model has been in conjunction with Petro-Canada's dispersant logistics problem. Petro-Canada faces a major problem of how to determine the best locations as well as quantities of chemical dispersants that should be stockpiled to respond to spills. This problem is especially relevant to spills which may occur during drilling operations off the coast of Newfoundland and Nova Scotia in the years ahead. Petro-Canada assigned the research team the task of making a preliminary evaluation of this problem.

The typical blowout scenario examined has been a 30-day spill of a 5,000 bbl/day discharge rate. Dispersant can be dispatched on scene by any one (or a combination) of three modes: aircraft, helicopter, or boat.

A thorough investigation of this problem, that is, a full-scale application of the Strategic Model, constitutes an enormous task, considering the vast data collection effort that would be necessary to establish a "regional profile" database for such an extended geographical area. Such an effort, if it were actually to be undertaken at all, should be preceded by a limited-scope application of a simplified version of that model, that could somehow bypass the complex Trajectory and Damage Assessment calculations. Such a bypass is possible and is facilitated by the modular structure of the overall model. In that respect, no modifications in the logic of the Strategic Model had to be made to decouple that model from the Trajectory and Damage Assessment Models. This bypass involved using a surrogate measure of damages, that is, an easily-measurable variable that could be used to reflect the magnitude of those damages. For the Petro-Canada problem, the role of such a surrogate was played by the total volume of undispersed oil.

Several scenarios have been investigated in the Petro-Canada problem. The base-case analysis seems to indicate that the system that minimizes the expected volume of undispersed oil consists of three locations, with helicopter response originating from the first two and aircraft response originating from the third.

4.3 Port of Charleston Case

Another application of the model is being conducted with the U.S. Navy Facilities Engineering Command for the Port of Charleston, South Carolina. The port's exposure to oil spills with their resulting cleanup costs and damages will be analyzed for three sets of assumptions: that no cleanup action is taken, that the existing levels and locations of cleanup capacity holds, and that an optimal level and location plan for cleanup capacity is followed.

The challenging feature for this test of the model is its applicability to oil spills originating near and affecting ports and inland waterways. The immediateness of the threat, the potential of high value damage, the confined and complex geomorphology, and the necessity for a prompt and decisive response are key issues in the study.

Input data for the Charleston, South Carolina study included the following:

- Assumptions as to the number and size of spills in a typical year, developed from historical data and port records.

- The cost of cleanup and damages sustained by the various parties, following the Outer Continental Shelf Oil Pollution Compensation Fund, the most detailed federal statute in effect.

- Cleanup equipment available for the port.

- Results of that section of the Legal Model which analyzes the costs and damages sustained as a result of the oil spills in terms of who ultimately bears them.

To predict the damages caused by oil that will be spilled under a given response policy, one needs information about the trajectory of the spilled oil, the quantity of marine resources, and the effects of the oil on the resources. The first question is calculated by the Trajectory Submodel, but information on the other two must be collected by the user. Taking into account the complicated and still undefined nature of how oil affects marine organisms and other resources, and the difficulties in collecting data on the resource locations, it is clear why this problem is not yet well formulated or solved.

The task of attributing monetary values to predicted damages is difficult because the economic theory related to the concept of social cost is not well developed. For instance, consider the death of a seal, a protected species. The damage caused by this loss can hardly be expressed by its market value. Its death also represents ecological damage not included in its market price and for which no evaluation of economic theory exists. In such cases the only alternative is to ask the user to provide the model with estimates according to his judgment.

4.4 Potential Use of the MIT Oil Spill Model by the U.S. Coast Guard

Following is a discussion paper that was presented by Lieutenant Gary Reiter, Assistant Chief, Pollution Response Branch, U.S. Coast Guard Headquarters. The opinions expressed herein are those of Lieutenant Reiter and they are not necessarily those of the United States Coast Guard.

A person using a computer model to aid in the decision-making process must remember that assumptions concerning variable factors may be misleading. Recovery efficiency of skimmers and pumps vary drastically with types of oil, sea conditions, and the manner of use. If the Coast Guard skimming barrier is deployed in a dynamic mode, the towing vessels must be capable of maintaining 1 knot to prevent entrainment of collected oil. However, running at this speed is very difficult for most Coast Guard vessels, and Coast Guard On-Scene Coordinators (OSC) are usually forced to use other, readily available, vessels for spill operations. While the Coast Guard open water recovery system is an excellent tool for recovering various refined products and light crudes, it could not pick up the weathered oil from the Ixtoc I spill, for instance. (On June 3, 1979 there was a blow-out on the Ixtoc I drilling rig located in the Bay of Compeche. During the course of a year, millions of barrels of oil washed ashore on the east coast of Mexico).

Many of the assumptions made about tackling oil spills, such as having suitable vessels to deploy equipment, are beyond the control of the government or private parties responsible for cleanup activities. The availability of commercial equipment in the local area depends on economic incentives for the private cleanup contractor to maintain equipment. In an area which historically has had few spills, sufficient equipment to deal with a major incident probably will not be readily accessible. Another variable controlled by economics is the availability of barges or vessels to accommodate large quantities of recovered product. Even if an OSC has maximum recovery capability, without storage the operation is limited. In 1980 it was almost impossible to charter a barge in the Gulf for any price, but in 1982 numerous barges were available at reduced rates.

The MIT Oil Spill Model addresses damage assessment in several ways, but misses some primary difficulties. It assumes that there are quantifiable costs for damage, even though the value of natural resources varies with the assessor and the accounting procedure used to tally the costs. This also applies to a certain extent on damages accrued to fishing and tourism. For example, Chesapeake Bay fishermen suffered a low yield of crab in 1983. Had a spill occurred in the recent past, a hasty assessment might have falsely implicated the spill as the cause. Damage costs may not be reduced as cleanup capability increases. Public opinion varies in regions of the US, and this affects damage assessment and cleanup efforts.

The primary value of this type of model to Coast Guard cleanup operations will be in evaluating local capabilities and contingency plans. The model is a useful tool for evaluating response actions following actual incidents. An inherent danger, however, is the natural tendency to use the model results to grade rather than to evaluate performance, and without regard for the many variable factors.

Another valuable use for the model is as a training aid. One of the major disadvantages of training exercises is that in responding to hypothetical oil spills, one receives no quantitative feedback regarding the effects of one's decisions and how different decisions would have affected the outcome. It would be interesting to apply this model to an OSC/RRT simulation or in the canned exercises conducted at the Marine Safety School in Yorktown, Virginia.

After the model has been evaluated in these types of situations and OSCs are aware of its positive and negative values, applications for use during actual spill situations may become more feasible and frequent.

5.0 A DISCUSSION OF THE VALUATION OF NATURAL RESOURCES

The following is a discussion paper that was presented on October 13, 1983 by Norman Meade, Economist with the National Oceanic and Atmospheric Administration, Ocean Assessment Division (N/OMS31) in Rockville, Maryland. The opinions expressed in this paper do not necessarily represent the official views of the National Oceanic and Atmospheric Administration.

The allocation of society's endowment of publicly owned natural resources among competing users has, in recent years, become the subject of intense, often bellicose, political debate. Increased demand for the goods and services provided by these natural resources has raised the degree of conflict to a point where our court system and governmental institutions, at all levels, are beseeched with demands to remedy disputes. This conflict is largely because traditional property rights and organized markets of exchange do not exist for many publicly owned natural resources.

Natural resource economics is concerned with the study of the production and exchange of goods and services from scarce natural resources to satisfy unlimited human wants and needs. It is possible to define two basic types of natural resources: those that are privately owned and from which economic profits can be extracted; and those that are public property, and usually yield economic profits only in limited circumstances because they are managed by governmental entities to enhance the public welfare rather than private well-being. In general, both privately and publicly owned natural resources produce a mixture of what are called market and non-market goods and services. The former are bought and sold in organized markets and possess well defined exchange prices while the latter do not have the benefit of organized markets and explicit prices to facilitate their trade. A forest which is corporately owned and managed for the purpose of providing commercial timber is an example of a private natural resource producing a market valued good. The coastal fisheries of the United States are good examples of publicly owned resources which produce a mixture of both market goods, such as commercial fish, and non-market goods such as recreational fishing stocks.

When a natural resource is not traded in a market setting based on explicit prices it is subject to market failure. That is, the supply and the demand for the goods and services produced by that resource can become unbalanced. In such instances, a government agency is frequently asked to step in to alter the supply or demand or both, to try to put them back into equilibrium. In so doing, the government often creates an artificial market by defining property rights and in some cases regulating quantity and prices. Hence, we find the government involved in managing a wide array of natural resources, such as fish and wildlife, and land use around public water supplies and in public parks. The involvement by government institutions in the problem of pollution control is directly related to the existence of market failure. If individuals could purchase the exact amount of clean water they demanded, there would be no need for public officials to determine its most beneficial allocation from a social point of view. But, although there are well defined property rights, no organized market or explicit prices exist for this commodity and hence public regulators must step in to do the job. For privately owned goods such as steel, corn and automobiles, we can generally rely on the market mechanism to set prices and allocate their production and exchange.

Though there are countless examples of man's action or inaction creating costs or benefits which fall outside of the normal market place, there is no justification for assuming that the affected goods or services have zero value just because they do not have established prices and are allocated by government regulation. It is important to keep in mind that natural resources do not in themselves have intrinsic worth. Their monetary value is an abstract concept assigned by an economic system according to how successfully the goods and services those resources produced satisfy human demands in comparison with other, substitute commodities.

One may accept the idea that non-market benefits and costs exist, yet object to their quantification on moral or professional grounds. Moral arguments are beyond the economist's purview. Professional objections must be based on acceptability of method and the precision of estimates. If judicial codes, case law and legislative statutes require monetary estimates of resource values, such as in benefit-cost analyses or in environmental pollution damage compensation schemes, omitting an estimate of the non-market values, on whatever grounds, places a value of zero on those goods and services and undervalues the resource. Arguments whether to include such values in our social decisionmaking are largely political. However, based upon the legislative and judicial mandates of the past decades, the need for such information is apparently here to stay as an integral part of the process by which society manages its stock of natural resources.

The goods and services derived from marine-based resources represent a mixture of non-market and market values. When an oil pollution event occurs, for example, both market and non-market losses can be expected. Fishermen lose income if fish stocks are damaged, and the potential fish consumers lose satisfaction because they must turn to other less desirable food substitutes or risk eating contaminated fish. These losses can be fairly easily quantified using historical data on fisheries supply, demand and prices. But what about the non-market losses associated with the aesthetic insult of an oil spill fouling a popular recreational beach? There are no readily available statistics to evaluate the size of those losses because there is no market of exchange to provide them. In such cases, economists must rely on any number of alternative techniques which have been developed for addressing this type of problem.

Contingent valuation is a method of questioning randomly selected users of a non-market resource, such as a public beach, to try to determine their implicit valuation of the unpriced goods and services that are produced. Various questionnaire techniques have been developed to try to elicit these types of values, such as the individuals' willingness to pay for better beach quality or their willingness to accept a payment for reduced beach quality. The contingent valuation method suffers from the criticism that it is hypothetical in nature and that questionnaire respondents either do not know the exact monetary value of a particular non-market good or service they are consuming, or they may have strategic biases which mitigate against their revealing its true value. For example, the respondents might feel that if a public agency learns how highly they value a given resource, they may be charged a fee to use it.

The travel cost method analyzes the monetary expenditures made by consumers of a non-market resource, such as marine recreational fishing, bird watching, etc. Here it is assumed that the number of trips individuals make to a given recreation site depends on how much it costs them to get there. One problem with adding up expenditures for gas, clothing, food, lodging and the like is that these items may have other intrinsic values of which recreation is only a part.

The hedonic function approach has gained notoriety in recent years, largely due to the controversy surrounding it rather than for its successful implementation. This technique is based on the relatively simple concept that consumers derive value (utility) from a bundle of characteristics associated with a particular resource. Thus, the value of a beach day can be expressed as a function of the degree of cleanliness of the beach, the amount of crowding, accessibility, etc. Through complicated statistical manipulations of large sets of data a value can be inputted to the resource. Several empirical problems associated with this analytical technique remain unresolved at the present time, however. Until they are successfully addressed, the hedonic approach will remain largely an intellectual curiosity rather than a useful analytical tool. Its one compelling feature is that it uses actual market transaction data, rather than relying on hypothetical information as does the contingent evaluation approach. Thus, further development of this technique appears warranted.

While other valuation techniques seem to pass in and out of vogue in rapid succession, the ones just outlined are the most commonly employed today. The one central thread that links all of them is that none provide a perfect estimate of the value of non-market resources. Given the increased demand for such values to aid in governmental and judicial decision-making, economists are under increasing pressure to perfect their techniques. This is evidenced by the growing amount of empirical research being devoted to the subject. Two examples will be mentioned briefly.

The first is a recently completed study of the economic costs of the Amoco Cadiz petroleum tanker spill off the coast of Brittany, France in 1978. The National Oceanic and Atmospheric Administration (NOAA) commissioned that project in order to test various marine resource valuation techniques in preparation for their implementation routine basis under the then pending (and now enacted) "Superfund" legislation (P.L. 96-510).

Approximately 30 percent of the 67 million gallons of oil spilled from the Amoco Cadiz washed ashore on Brittany, directly affecting about 400 kilometers of shoreline. The remainder of the oil was dispersed at sea or evaporated. The spill had adverse effects on marine resources, such as aquacultured oysters and various species of finfish, on the tourist industry, and on the satisfaction of those who expected to, or did, vacation on the Brittany coast that year. The economic damages associated with those impacts, plus the cost of the cleanup effort, and the value of the cargo and ship constitute the major categories of economic damage. Total costs were estimated to range between $190 and $290 million in 1978 dollars. The methods used to estimate those costs and a complete description of the results are presented in the 1983 report, "Assessing the Social Costs of Oil Spills: The Amoco Cadiz Case Study," U.S. Department of Commerce, National Oceanic and Atmosphere Administration, Washington, D.C. pp. 144. It was the first time a comprehensive economic study of damages to natural resources resulting from a major oil (or hazardous substance) spill had ever been undertaken. NOAA hopes that its research can serve as a point of departure for further improvement in this emerging field of inquiry.

The second research effort is the MIT Oil Spill Model, which is the first attempt of its kind to build a state-of-the-art, comprehensive computerized model for valuing economic losses associated with damages to marine resources from oil spills. The flexibility of the model -- all assumptions and algorithms can be easily modified — should make it a valuable tool in the rapidly evolving field of natural resource management.

For example, the MIT model can optimize the emergency response to oil spill cleanup operations by directing equipment and manpower where they can alleviate the greatest amount of resource damage at the lowest cost. Furthermore, the model should be highly useful to federal and state trustees as a basic analytical structure around which to build a natural resource damage assessment model. This would greatly assist them in implementing that component of the new Superfund law which provides for monetary compensation to parties injured by the loss of use of natural resources resulting from hazardous substances spills.

The central challenge remaining for the MIT modeling team, and for all analysts attempting to place monetary estimates on the value of the goods and services produced by natural resources, is to improve our capability for estimating the value of the non-market components. While success in the near term is not very likely, through diligent and creative research progress on this problem can be made over time. In the interim, we can expect a great deal more litigation and political debate over the way in which society allocates the use of publicly owned natural resources.

6.0 SUMMARY

The initial applications of the MIT Oil Spill Model provide encouraging evidence that this is a valuable tool for assessing and coping with accidental oil spill problems. Because the model is still under development, it must be implemented by either one of the investigators, Nyhart or Psaraftis. They can be reached at the MIT Ocean Engineering Dept., Bldg. 5-213, 77 Massachusetts Ave., Cambridge, MA 02139.

Technical descriptions of the five sub models are available in draft form from the MIT Sea Grant Program. These draft reports are listed in Section 7.0, "Related Reading". Write to the MIT Sea Grant Program, Marine Information Center, 292 Main Street, Cambridge, Massachusetts 02139 for more information.

7.0 RELATED READING

"Assessing the Social Costs of Oil Spills: The Amoco Cadiz Case Study" U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Washington, D.C. pp. 144.

Baird, A.V., K. Johnson, R. Corwin, P. Csik, Draft Report "Oil Spill Cleanup Economic and Regulatory Model - Volume 4: the Trajectory and Damage Assessment Models." MIT Sea Grant Report, October 1982.

Campbell, Brad, Edward Kern, and Dean A. Horn. Impact of Oil Spillage From World War II Tanker Sinkings. MITSG 77-4. NTIS: PB-265 857/AS. Cambridge: Massachusetts Institute of Technology, 1977. 85 pp.

Demis, Dimitrios, "Oil Spill Management: The Damage Assessment Model and The Spatial Allocation of Cleanup Equipment." Thesis, MIT Ocean Systems Management, May 1983.

Devanney, John W., III, Joseph B. Lassiter III, et al. Primary Physical Impacts of Offshore Petroleum Developments: Report to Council on Environmental Quality. MITSG 74-20. NTIS: COM-74-11125/AS. Cambridge: Massachusetts Institute of Technology, 1974. 432 pp.

Devanney, John W., III, S. Protopapa and R. Klock. Tanker Spills, Collisions and Groundings. MITSG 79-14. NTIS: PB299204/AS. Cambridge: Massachusetts Institute of Technology, 1979. 105 pp.

Milgram, Jerome H. Being Prepared for Future Argo Merchants. MITSG 77-10. NTIS: PB-269 696/AS. Cambridge: Massachusetts Institute of Technology, 1977. 48 pp.

Milgram, Jerome H. and Robert Van Houten. A Flume for the Study of Contained Oil Slicks. MITSG-77-19. NTIS: PB-272 160/AS. Cambridge: Massachusetts Institute of Technology, 1977. 41 pp.

Milgram, Jerome H. and Robert J. Van Houten. Mechanics of a Restrained Layer of Floating Oil Above a Water Current. Reprint: J. of Hydronautics, Vol. 12, No. 3, July 1978, pp. 93-108.

Moore, Stephen F., Robert L. Dwyer, and Arthur M. Katz. A Preliminary Assessment of the Environmental Vulnerability of Machias Bay, Maine, to Oil Supertankers. MITSG 73-6. NTIS: COM-73-10564. Cambridge: Massachusetts Institute of Technology, 1973. 162 pp.

Moore, Stephen F., Gary R. Chirlin, Charles J. Puccia, and Bradley P. Schrader. Potential Biological Effects of Hypothetical Oil Discharges in the Atlantic Coast and Gulf of Alaska. MITSG 74-19. NTIS: COM-74-11089/AS. Cambridge: Massachusetts Institute of Technology, 1984. 121 pp. Order from NTIS.

Naess, Erling D., William M. Benkert, James A. Cole, Jr., Jerome H. Milgram, and Evelyn F. Murphy. Oil Pollution of the Oceans: A Tanker Owner's Perspective. The Seventh Annual Sea Grant Lecture. MITSG 79-1. NTIS: PB297771/AS. Cambridge: Massachusetts Institute of Technology, 1979. 32 pp.

Nyhart, J.D., H.N. Psaraftis, W.S. Laird, "The Legal Environment Component of Oil Spill Cleanup Model," 1981 Oil Spill Conference, Atlanta, March 1981.

Nyhart, J.D., H.N. Psaraftis, Draft Report "Oil Spill Cleanup Economic and Regulatory Model - Volume 1: Main Report," MIT Sea Grant Report, October 1982.

Nyhart, J.D., W.S. Laird, A.V. Baird, Draft Report "Oil Spill Cleanup Economic and Regulatory Model - Volume 5: The Legal Model," MIT Sea Grant Report, October 1982.

Nyhart, D., Psaraftis, H., "First Experiences with the MIT Oil Spill Model." Proceedings of Oil Spill Conference (Prevention, Behavior, Control, Clean-up), February 28 - March 3, 1983, San Antonio, Texas. pp. 301-305.

Pollack, A., K. Stolzenbach. Crisis Science: Investigations in Response to the Argo Merchant Oil Spill, MITSG 78-8, 1978.

Psaraftis, H.N., A.C. Baird, J.D. Nyhart, "National Response Capability to Oil Spills: A Systems Approach," OCEANS '80 Conference, Seattle, September 1980.

Psaraftis, H.N., D.A. Betts, "A Preliminary Investigation of Petro-Canada's Oil Spill Dispersant Logistics," Report to Petro-Canada, October 1982.

Stewart, Robert J. The Interaction of Waves and Oil Spills. MITSG 75-22 NTIS: PB-262 458/AS. Cambridge: Massachusetts Institute of Technology, 1976. 201 pp.

Stolzenbach, Keith D., Ole S. Madsen, E. Eric Adams, Andrew Pollack, and Cortis Cooper. A Review and Evaluation of Basic Techniques for Predicting the Behavior of Surface Oil Slicks. MITSG 77-8. NTIS: PB-268 220/AS. Cambridge: Massachusetts Institute of Technology, 1977. Also through the Ralph Parsons Laboratory for Water Resources and Hydrodynamics. 205 pp.

Tharakan, G.G., H.N. Psaraftis, Draft Report "Oil Spill Cleanup Economic and Regulatory Model - Volume 2: the Spill Incidence and Strategic Models," MIT Sea Grant Report, October 1982.

Yaroschak, P.J., "New Directions in Oil Spill Contingency Planning," 1983 Oil Spill Conference, San Antonio, March 1983.

Ziogas, C.O., H.N. Psaraftis, Draft Report "Oil Spill Cleanup Economic and Regulatory Model - Volume 3: the Tactical and Operational Models," MIT Sea Grant Report, October 1982.

8.0 APPENDIX

MIT Marine Industry Collegium Workshop #35
Case Studies of the MIT Oil Spill Model
October 13, 1983
Little Kresge Auditorium
Massachusetts Institute of Technology
Cambridge, Massachusetts

AGENDA

8:30 Registration & Coffee

9:00 Welcome - Professor Chrys Chryssostomidis
Director, MIT Sea Grant Program
Margaret Linskey, Assistant Manager, MIT Marine Industry Collegium

9:15 Project Background to Date
Professor J.D. Nyhart - MIT Sloan School of Management & Department of Ocean Engineering

9:45 Description of the Sub-Model Components
Professor Harilaos Psaraftis - MIT Department of Ocean Engineering

10:40 Coffee Break

11:00 Description of the Sub-Model Components (Continued)
Professor J.D. Nyhart - MIT Sloan School of Management & Department of Ocean Engineering

11:30 Case Study I: Application of the Model to New England Region: Argo Merchant Spill, Long Term Planning
Professor Harilaos Psaraftis - MIT Department of Ocean Engineering

12:00 Lunch
Mezzanine Lounge Student Center

1:00 Case Study II: Petro-Canada
Dimitri Dascalopoulos - Graduate Student, MIT Department of Ocean Engineering

1:30 Case Study III: Port of Charleston, South Carolina
Professor H. Psaraftis

2:00 Use of Analytical Models by the U.S. Coast Guard in their Pollution Response Activities
Lt. Cdr. Gary Reiter - U.S. Coast Guard

2:30 Evaluation of Damages to the Marine Environment
Mr. Norman Meade - Office of Ocean Research Coordination & Assessment, NOAA

3:15 Break

3:40 Demonstration of Computer Model

4:30 General Discussion

5:00 Wine & hors d'oeuvres
Hart Nautical Museum, MIT Building 5 First Floor