March 2004

ADVANCING OIL SPILL RESPONSE IN ICE-COVERED WATERS

prepared for

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Cordova, Alaska

and

United States Arctic Research Commission
Arlington, Virginia and Anchorage, Alaska

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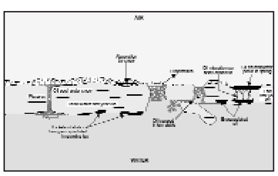
Cover photo: Diver's view of frazil ice crystals beneath a solid sea ice sheet during an experimental spill of emulsified crude oil. Note orange fabric skirt hanging through the ice to contain the spill (background), and oil drops coating the underside of the ice (foreground). Ref. Buist et al., (1983) in Bibliography.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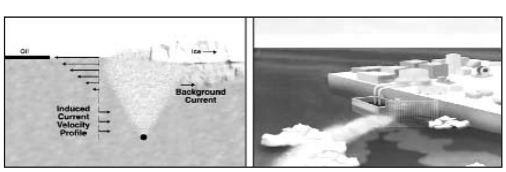

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ACKNOWLEDGEMENTS

The Prince William Sound Oil Spill Recovery Institute (OSRI) and the United States Arctic Research Commission (USARC) wish to thank the project steering committee and, particularly, David Dickins for the time and personal expertise they contributed in preparing and reviewing preliminary materials, and in planning the workshop. The goal to review and prioritize a long list of R & D projects was achieved with the assistance of both experts in the field and the general public. Appreciation is extended to those who responded to the web posting soliciting public comment on the draft document prior to the workshop. Finally, we thank the workshop attendees who actively debated the issues over a two-day period and contributed greatly to finalizing the core set of priorities presented in this report.

The project steering committee included: Nancy Bird, Director, Prince William Sound Oil Spill Recovery Institute; Lawson Brigham, United States Arctic Research Commission; Doug Lentsch, Cook Inlet Spill Prevention and Response; Joseph Mullin, U.S. Minerals Management Service (MMS); Charlene Owens, ExxonMobil Upstream Research Company; Walter Parker, Prince William Sound Oil Spill Recovery Institute; Leslie Pearson, Alaska Department of Environmental Conservation (ADEC); and John Whitney, NOAA Hazmat Alaska.

The following individuals are thanked for their review of preliminary materials and for providing technical comments and feedback from their own personal experience: Ian Buist, SL Ross Environmental Research Limited; Alan Allen, Spiltec; Merv Fingas, Environment Canada; Charlene Owens, ExxonMobil Upstream Research Company; Hans Jensen, SINTEF; Ian Lambton, Riverspill Response Canada; Kari Lampela, Finnish Environment Institute; Nick Glover and Ed Thompson, BP Exploration (Alaska) Inc.; Brad Hahn, Alaska Clean Seas; Doug Lentsch, Cook Inlet Spill Prevention & Response, Inc.; Leslie Pearson, Alaska Department of Environmental Conservation; Edward Owens, Polaris Applied Sciences; Bill Lehr, NOAA Hazmat; Mark Meza, US Coast Guard; Joseph Mullin, MMS; Gary Sergy, Environment Canada; Laurie Solsberg, Counterspil Research; Ron Goodman, Innovative Ventures; Anatoliy Polomoshnov, Sakhalin Oil and Gas Institute; Melanie Engram. Alaska Satellite Facility, Geophysical Institute, University of Alaska Fairbanks; and Jorma Rytkonen, VTT Technical Research Centre of Finland.

Publication design and layout by TerraGraphica of Anchorage, Alaska, ecline@alaska.net.

FOREWORD

The Prince William Sound Oil Spill Recovery Institute (OSRI) was established by Congress in 1997 to support research and educational and demonstration projects, all of which address oil spills in Arctic and sub-Arctic marine environments. The Institute supports a variety of applied and ecology-related projects. Addressing deficiencies in our ability to respond to oil spills in ice-covered waters is a priority, and developing an oil and ice research plan is central to OSRI legislated mandates. This report is the result of a think-tank workshop organized to refine and prioritize many research and development project ideas into a prioritized list. OSRI will use this document to help determine how to most effectively allocate its resources and build partnerships that will improve our prevention and response capabilities in ice-covered waters.

The United States Arctic Research Commission was established by the Arctic Research and Policy Act of 1984 (as amended in November 1990). The Commission, whose seven members are appointed by the President, assesses national needs for Arctic research and recommends to the President and the Congress research policies and priorities that form the basis for a national Arctic research plan. During its entire 20-year existence, the Commission has been concerned with the lack of adequate research on oil spill cleanup techniques and procedures in ice-covered waters. In May 1992 the Commission issued a special report entitled *Research Needed to Respond to Oil Spills in Ice-infested Waters*. Among the recommendations were a call for increased knowledge of in situ burning, enhanced applied research and field testing, research on oil detection and cleanup alternatives, ecological research, and expanded international cooperation. This new report, sponsored jointly with OSRI and an international team of experts, continues the Commission's strong commitment to improving U.S. and international research on a suite of effective responses. Greater marine access throughout the Arctic Ocean in the coming decades makes it imperative that this research be given an appropriate priority by both responsible federal agencies and the private sector.

SUMMARY AND CONCLUSIONS

Goals & Objectives

The objective of this project is to identify programs and research and development projects that improve the ability of responders to deal with accidental oil spills in fresh or salt-water marine environments where there is ice. This includes spills that occur on top of or underneath solid, stable ice extending out from shore (land-fast), into an area of drifting ice floes (pack ice), or onto an ice-covered shoreline.

Oil spills in ice are a subject of great concern to corporations, local residents, and government agencies participating in oil exploration, production, and transportation. Currently, areas that are of special concern are Cook Inlet, the Beaufort Sea (including the North Slope of Alaska), Sakhalin Island offshore, and the Norwegian Barents, Baltic, and Caspian seas. As reserves are depleted in more accessible areas, cold frontier regions will increasingly receive attention in the areas of exploration and production.

In most areas of the world, the greatest need is to develop a credible and effective response to oil that has been spilled in moving, broken pack ice in the ocean, lakes or rivers. Practical response strategies are, in most cases, already available to deal with spills in a stable, fast-ice environment. A notable exception involves the lack of operational tools to detect or map oil in any ice type.

Background & Evolution

This project grew out of a desire to further explore the unusually broad range of oil spill-related topics presented at the *2000 Alaska Clean Seas International Oil and Ice Workshop* in Anchorage, Alaska. The program covered topics such as detection and monitoring, logistics, operational lessons from case studies, burning, mechanical recovery, and dispersants.

In 2001, OSRI funded a grant application by DF Dickins Associates Ltd. to identify critical deficiencies in the current body of knowledge regarding oil spills that occur in the presence of any form of ice. The second and final phase of the project began in the spring of 2003. The goal: to recommend research and development programs and projects to improve future response capabilities, and to publish the findings for international distribution under the joint sponsorship of OSRI and USARC.

Methods

More than 60 ideas and research concepts extracted from presentations made at the *2000 International Oil and Ice Workshop*, were the springboard for this project. During the first phase, material was screened for ideas with the most potential for improving response effectiveness. During the second phase, these initial findings were further analyzed and discussed using a series of methodologies, including soliciting comments from the research community, government agencies, industry and the public.

This process culminated in November 2003 during a two-day workshop in Anchorage. This small group of selected specialists represented a cross section of interests and backgrounds for thoroughly evaluating the benefits and drawbacks of the ideas and comments received, and developing a priority list of recommended program areas and related projects. Seven technical areas were identified as priorities, along with a number of other important program ideas, and universal research and development elements.

Overview of Findings

Consistent long-term funding is needed for developing and improving response options for dealing with accidental oil spills in ice-covered waters.

Spill response operations in ice and open water are fundamentally different. These variances must be recognized when determining the most appropriate strategy for dealing with oil in specific ice conditions and seasons, including freeze-up, winter, and break-up. Because of the vastly different ice environments and oil-in-ice situations, over-reliance on a single type of response will likely result in inefficient, ineffective cleanup after an actual spill.

Successful spill response hinges on more than the immediate availability of the best technology. Several important non-technical issues raised during the course of this project should also be considered when planning spill response programs and operations:

1) Encouragement of more flexible regulations so that all possible response tools can be considered for use from the outset of a response. Regulations must account for unique aspects of oil-in-ice response compared with open water response, such as: natural containment

offered by the ice, dramatically reduced spreading rates, and natural shore protection.

2) Development of long-term education and public outreach programs to explain the advantages and disadvantages of different response strategies.
3) Application of biological sciences as part of net environmental benefit analysis (NEBA) to assess the relative merits of different response strategies.

Responders need to have access to all available response tools in a timely manner. Improvements in this area will require honest and open communication among industry, government, and the public. At the same time, sustained, long-term education and public outreach programs will help facilitate more effective response decisions, which maximize the capabilities of different technologies.

A series of successful Arctic field experiments in the 1970s and early '80s was largely responsible for helping in-situ burning become accepted as the most effective oil recovery strategy in situations involving spills in ice covered waters. There is an extensive body of knowledge on the fundamentals of burning in different ice types. New research and development in this discipline needs to concentrate on measures and techniques for expanding the operating window for burning in ice, such as when spills result in thin films occurring among ice floes. The successful development of chemical herders could enhance burning in these marginal situations.

Mechanical recovery of oil spills in pack ice is limited by drifting ice interrupting conventional containment and skimming activities. Improving the effectiveness of existing mechanical equipment is worthwhile, though such developments are unlikely to produce substantial gains in response effectiveness. New techniques to deflect and separate oil and ice—such as prop wash or pneumatic bubblers—may enable mechanical systems to encounter and recover oil at higher rates in the presence of drifting ice.

Dispersants are used in many areas of the world as a primary response strategy, and to complement other techniques. In cold-water environments where there is also ice, dispersants have been viewed as having the potential for only limited success. Concerns include the lack of natural mixing energy due to the dampening effects of the ice, and the tendency for oils to become viscous at low temperatures. Recently, though, promising results from industry-sponsored tank tests have spurred a reexamination of dispersants as a possible clean up strategy for certain oil-in-ice situations. Using icebreakers or other vessels to introduce the required mixing energy, in combination with a dispersant formulated for longer retention by viscous oils, could lead to dispersants becoming a practical response option for oil spills in ice. Research in this area is still at an early stage, and more research and development needs to be undertaken before a definitive recommendation can be made.

The present inability to reliably detect and map oil trapped in, under, on, or among ice is a critical deficiency, affecting all aspects of response to spills in ice. Although there is still no practical operational system to remotely detect or map oil-in-ice, there are several technology areas where further research into ground-based remote sensing could yield major benefits. Examples include: Recent tests with optical beams for river spills, and Consideration of vapor detection (sniffer systems) for oil trapped in ice. Aerial remote sensing for detecting oil in ice remains an elusive goal.

Transferring oily waste that contains a mixture of small ice chunks or slush under freezing temperatures presents a major challenge. Considerable progress has been made in dealing with highly viscous products, but these projects have not attempted to add ice and freezing conditions.

Conducting field spills with oil for experimental purposes is not allowed in many parts of the world. This is a serious drawback to developing more effective response procedures, improving personnel training, and testing equipment for responding to spills in ice. Although oil simulants have been considered as a means of securing permits and allowing more realistic field trials, currently there is no product that mimics real oil without impacting the environment.

Regular full-scale field trials with oil are essential to: (1) Validate and prove response technologies and strategies developed in laboratory or meso-scale tests; (2) Understand the fate and behavior of oil under different marine conditions; (3) Train and drill responders with real oil (in the same way that firefighters develop and maintain proficiency by practicing on real fires); (4) Develop operational guidelines for specific technologies; and, (5) Build confidence and trust among all stakeholders in oil spill response (public, industry and government). There is a particular need for further tests in dynamic pack ice.

Field trials with oil can be designed as comprehensive international programs that integrate complementary scientific, engineering and operational elements. A substantial body of experience shows that rigorous program design and execution results in trials being carried out in a safe and environmentally responsible manner with a high degree of confidence.

Joint funding is critical to launching significant new research in the field of oil and ice response. International cooperation from government and industry participants is required to make substantial progress in the most important research and development areas. Currently, centers of expertise are scattered around the globe with a small number of researchers and organizations actively involved in ongoing research.

Future developments in the Arctic oil spill response field require cooperative funding by government agencies and oil industry operators. Multi-national corporations involved in oil development in regions such as offshore Sakhalin Island, the Siberian Arctic, the Caspian Sea, and Alaska have a strong interest in pursuing research in this field.

1.0 STUDY BACKGROUND

Presentations at the 2000 Alaska Clean Seas (ACS) International Oil and Ice Workshop formed the initial source of ideas for this project. More than 300 participants from around the world attended. All were concerned with issues of oil fate and behavior, spill risk, and spill response in ice-covered waters. Key topics presented were: detection and monitoring, logistics, operational lessons from case studies, burning, mechanical recovery, and dispersants.

The following year, the Prince William Sound Oil Spill Recovery Institute (OSRI) funded a grant application by DF Dickins Associates Ltd. to identify critical deficiencies in the existing knowledge base on oil spills occurring in any form of ice. The 2000 Workshop proceedings were used to develop a preliminary listing of spill response deficiencies and possible solutions. Additional sources included: (1) An extensive review commissioned by Alaska Clean Seas (ACS) to examine Beaufort Sea spill response, ice conditions, oil behavior and monitoring (Dickins et al., 2000); and, (2) Further comments received from the original workshop authors. Findings from this first phase are contained in a technical report issued to the OSRI (Dickins 2002).

The second and current phase of the project began in the spring of 2003 with the goal of recommending research and development programs and projects to improve future response capabilities. The process used ensured maximum opportunity for comment and input from a wide range of interested parties. Steps in this process included:

- Appointing a steering committee to help define the scope of the project and methodology **(Appendix A)**

- Distributing a simplified extract of the 2002 project report for comments and new ideas to approximately 50 key researchers in private, academic and government organizations worldwide **(Appendix B)**

- Posting a synopsis of research ideas, incorporating input from the engineering and science community on two web sites for public review and comment (OSRI and the Arctic Info maintained by the Arctic Research Consortium of the United States.)

- Holding a two-day workshop in Anchorage, Alaska, November 4-5, 2003, attended by a small group of specialists invited from government, industry and the consulting research community **(Appendix C)**. A key goal of the workshop was to finalize a set of priority ideas or programs with representative projects.

2.0 INTRODUCTION AND OBJECTIVES

The objective of this project is to identify areas where further research and development will improve the ability of responders to deal with an accidental oil spill in a fresh or salt-water marine environment in the presence of ice. Such an event could include spills of oil on top of or underneath solid, stable ice extending out from shore (land-fast), into an area of drifting ice floes (pack ice), or onto an ice-covered shoreline. **Figure 1 (page 6)** shows a schematic composite displaying a number of possible configurations of oil in ice.

Research into oil and ice behavior and the development of response strategies has traditionally involved a combination of laboratory small-scale tests, tank and basin meso-scale tests, and full-scale field trials. **Figures 2 and 3 (page 6)** show two examples of recent tank tests in North America: an evaluation of mechanical recovery devices at the Ohmsett facility in New Jersey (Buist and Dickins, 2002), and in-situ burning in slush and brash ice in the Alaska Clean Seas wave tank at Prudhoe Bay (Buist et al., 2003; Mullin et al., 2003).

Many significant technical advances in Arctic spill response can be attributed to a series of highly successful field trials with oil carried out in U.S., Canadian and Norwegian waters during the past 30 years. **Figure 4 (page 6)** shows such a project involving crude oil in pack ice off the Canadian East Coast in 1986 (SL Ross and DF Dickins, 1987). This was the first of only two experimental spills conducted at sea with oil in broken ice. The second was off the coast of Norway in 1993 (Vefsnmo and Johannessen, 1994).

The subject of oil spills in ice concerns corporations, local residents, and government agencies participating in oil exploration, production and transportation in areas such as: Cook Inlet, Sakhalin Island, and the Beaufort (including the North Slope of Alaska), Norwegian Barents, Baltic and Caspian Seas. As reserves are depleted in more readily accessible areas, the Arctic will receive increasing attention in exploration and production.

Figures 5-8 (page 6) show examples of offshore exploration and production structures and tanker operations in areas where ice is present for part of every year.

Strategies and techniques for dealing with oil in ice have been studied extensively over the past 20 years. Dickins and Buist (1999) provide a summary of work in this field with a selection of key references. **Figures 9 and 10 (page 7)** show examples of mechanical recovery and in-situ burning in ice.

In addition to the 2000 ACS Workshop in Anchorage, other key reference sources for published papers on the subject of oil spill response in ice include:

- Proceedings—Environment Canada Arctic Marine Oil Spill Program (AMOP) technical seminars held annually since 1977
- Proceedings—Finnish Environment Institute Seminar on Marine Oil Spills in Ice held in Helsinki, November 2001

Two successful oil spill research projects in the Canadian Beaufort Sea from 1974 to 1981 (Norcor 1975, Dickins and Buist 1981) contributed to in-situ burning becoming accepted as a primary response strategy to deal with spills in ice.

Mechanical recovery has been demonstrated to be a practical strategy in solid, fast ice (Allen and Nelson, 1981; Alaska Clean Seas 1999). However, as shown in **Figure 11 (page 7)**, the effectiveness of conventional mechanical containment and recovery systems can be seriously degraded in broken ice (Bronson et al., 2002). Intensive international efforts to develop dedicated mechanical systems for operations in naturally broken ice have not progressed beyond the prototype stage (Mullin et al., 2003). Finland has developed full-scale operational systems to deal with relatively small ice piece sizes in Baltic shipping channels (Rytkonen et al., 2003).

To date, limited consideration has been given to the use of dispersants for spills in ice. Previous experience is summarized in Brown and Goodman (1996) and Ross (2000). Recent industry tests at the Ohmsett facility have shown new promise (ExxonMobil 2002, unpublished).

This project was initiated with the goal of objectively assessing all possible research and development ideas that could result in improving existing response tools for oil in ice.

3.0 METHODOLOGY TO SELECT RESEARCH AND DEVELOPMENT PRIORITIES

This project started with more than 60 ideas and research concepts derived principally from presentations made at the International Oil and Ice Workshop (ACS 2000). These ideas and concepts were screened in the first phase to create a subset, judged for having a moderate to high potential for improving response effectiveness. The term "response effectiveness", as used in this study, encompasses all activities associated with recovery or removal of oil from a marine environment, or reducing the impact and consequences of a spill in ice.

In the second phase of the project, the resulting subset of ideas was forwarded for in-depth analysis and discussion, according to the steps outlined in Sec. 1.0. Public comment covered issues such as the importance of burning oil in ice, using local knowledge to enhance response activities such as tracking and monitoring, developing school curriculum packages on oil spill response, and applying a systems approach to evaluating the optimum mix of response strategies in different situations.

During this project, a number of important non-technical program ideas, such as regulatory regimes and public education, were identified as being crucial to the acceptance and application of different response strategies. These ideas are described separately in this document as universal elements applicable to many research and development projects (Sec. 4.4).

3.1 Workshop Process

A short list of high priority program areas and associated projects was developed at a two-day workshop in Anchorage where participants had opportunities to weigh the benefits and drawbacks of all the ideas and comments received. Participants representing a broad range of interests and applied experience were invited from government regulatory agencies, the oil industry, oil spill response cooperatives, and engineering consulting firms (Attachment C).

The workshop screening and assessment process led to the selection of a number of priority program areas, as well as other valuable ideas identified in phase one of the project. These programs and ideas are described and outlined under the heading "Results" (Sec. 4).

The workshop was used to screen ideas, develop broad parameters for specific programs, and to identify specific project examples. Different ideas were assessed using the following questions as guiding criteria:

1) Does the program qualify as research and development?
2) Would research in this area make a difference to future response effectiveness?
3) Is the idea technically feasible, or does the research in this area have the potential to yield positive results? In some cases, the pressing need for a solution to a particular problem—as is the case with remote sensing of oil in ice—outweighs the historical evidence that research in this field may have only a limited chance of success.

Through this process, seven ideas or program areas were selected as having the greatest level of support among the participants at the workshop. These seven program areas are further developed in terms of scope and possible projects in Sec. 4.1. A point of emphasis: no one group of individuals can provide the final word on merit or value. The final selection of primary ideas (Sec. 4.1, 4.2) reflects the range of interests and experience of the workshop participants. Other important ideas and projects deserving attention are outlined in Sec. 4.3.

- Dispersants in Ice
- Oil Deflection
- Detection of Oil in Ice (Remote Sensing)
- Transfer of Icy, Oily Waste
- Chemical Herders
- Enhance Capabilities of Existing Mechanical Systems
- Simulants

In terms of *ice type*, the greatest need in most areas worldwide is to develop a credible, effective response to oil spilled in moving, broken, pack ice in oceans, lakes and rivers. Practical response strategies are available to deal with spills in a stable, fast-ice situation (Dickins and Buist, 1999).

In terms of *geographic applicability*, most research and development ideas described in this report are relevant to a variety of operating areas around the world (e.g. Baltic Sea, Sakhalin Island, Caspian Sea, Barents Sea, Beaufort Sea).

4.0 SELECTED PRIORITY PROGRAM AREAS & PROJECT EXAMPLES

The seven priority research and development programs selected during the workshop are presented here, along with other important ideas identified during the project. Costs quoted are strictly order of magnitude. Firm cost estimates require a detailed project definition.

4.1 Selected Priority Program Areas & Project Examples

DISPERSANTS IN ICE	
Need	Research whether dispersants will work in broken ice and identify oil types and scenarios where dispersants may have potential. Proof of effectiveness will increase response options to spills in broken ice.
Baseline Knowledge	There have been some tests conducted in cold water and limited tank and basin tests in broken ice (Brown and Goodman 1996 and ExxonMobil 2002, not published). ExxonMobil is currently developing project out lines around issues of dispersant mixing with icebreakers, and formulating and testing a new dispersant for viscous oils (2004-2005 completion of feasibility tests). The potential for dispersant effectiveness in fresh and brackish water is reported in Georges-Ares et al. (2001).
Political Sensitivity	Substantial—many jurisdictions will not consider dispersants out of fear of toxicity and related impacts. The extension of dispersants to an ice environment should not be politically more sensitive than gaining approval for use in open water.
Confidence	Medium—The effectiveness of dispersants in ice depends mainly on the available turbulent mixing energy. The energy level will determine whether it is possible to achieve permanent dispersion in the water column for a particular oil drop size with ice present (degree of resurfacing).
Timeline	On the order of five years or more, starting with some form of meso-scale testing in a large cold basin before proceeding with any full-scale field tests (Sec. 4.2)
Cost: Order of Magnitude	$500,000 per year
Other Issues	Shallow water constraints are related to concerns about suspended oil concentrations in the water column. Fresh water layers (e.g. off-Arctic river deltas) may alter the dispersion process or require a different dispersant formulation.
Example Projects	• Mixing with icebreakers (or other vessels) **See Fig. 12 (page 7)** • Developing a dispersant for viscous (cold) oils • Evaluating potential for long-term retention (e.g. assess ability of dispersants to remain with the oil as ice moves from a low- energy (internal pack) environment to a higher-energy ice margin. • Oil mineral aggregates • Effectiveness in fresh and brackish water • Fate and behavior and effects

OIL DEFLECTION OR REDIRECTION IN A BROKEN ICE FIELD	
Need	Separate oil and ice on the water surface to increase encounter rates for possible mechanical recovery or in-situ burning in fire booms. Even very low concentrations of ice seriously affect the performance of most skimmer systems through plugging and bridging. Conventional booms will quickly collect ice and subsequently lose oil as the flotation chambers are submerged or lifted out of the water. Deflection ideally directs oil to a collection and recovery area while moving the ice in another direction, or leaving it behind.
Baseline Knowledge	Limited—some older work with mechanical deflectors and water jets. Prop washing is a current technique used to clean oil out from under wharves at the Valdez, Alaska terminal. It has also been tried in Cook Inlet, Alaska. Feasibility of pneumatic diversion boom being validated at lab scale by ExxonMobil (2003). A series of projects are planned to further develop this concept in 2004 and 2005.
Political Sensitivity	None—mechanical recovery methods are accepted in all jurisdictions.
Confidence	Medium—Major constraint centers on the difficulty of moving oil a significant distance (beyond 20 to 30 meters).
Timeline	2-5 years
Cost: Order of Magnitude	$250,000 for Phase 1. Total program cost could reach $500,000 to $1 million.
Other Issues	Could also have applications for improved containment and recovery in non-ice areas such as rivers and streams. There is a diversity of projects to be considered. The ability of modern icebreakers to influence the surrounding ice over distances several times the vessel's beam may have applications to this program. **Fig. 12**.
Example Projects	• Propeller wash • Pneumatic diversion booms , the idea being to divert oil while letting ice pass. Example concepts **Fig. 13.** • Air jet blowers

Continued on Page 8

FIGURES

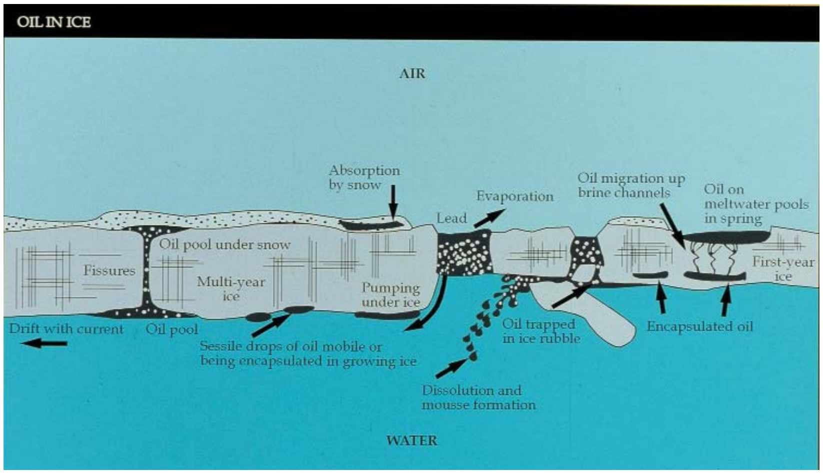

Figure 1
A schematic composite displaying a number of possible configurations of oil in ice.

Figure 2
Man-made ice field at the Ohmsett test tank, January 2002 (Buist and Dickins, 2002)

Figure 3
Burning in brash ice, ACS wave tank at Prudhoe Bay, Alaska, October 2002 (Buist et al., 2003)

Figure 4
Oil in slush among pancake ice off the Canadian East Coast, 1986 (SL Ross and DF Dickins, 1987)

Figure 5
Drilling platform, Cook Inlet Alaska

Figure 6
Northstar offshore oil production facility, North Slope Alaska. *Photo: D. Dickins*

Figure 7
Molikpaq, Canadian Beaufort Sea.
Photo: Gulf Canada Resources

Figure 8
Lunni Class tanker, Baltic Sea.
Photo: Neste Oy

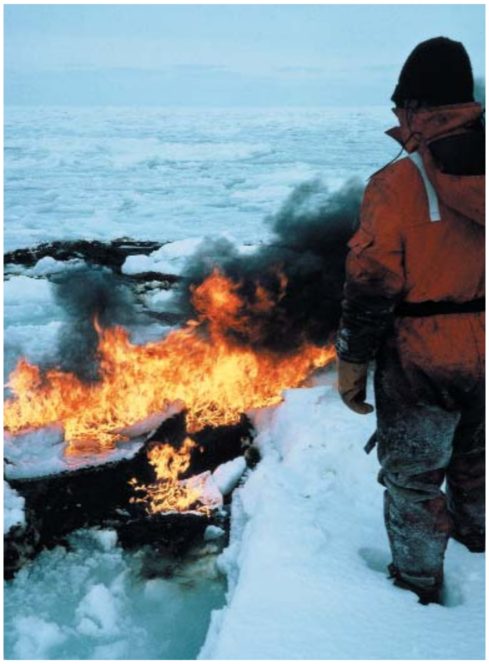

Figure 9
Burning crude oil in slush-filled lead off Nova Scotia, Canada, 1986. *Photo: SL Ross and DF Dickins, 1987*

Figure 10
Foxtail rope-mop skimmer in ice. *Photo: Alaska Clean Seas*

Figure 11
Conventional containment boom deployed in broken ice during field trials off Prudhoe Bay, Alaska, Spring 2000. *Photo: Alaska Clean Seas, 2000*

Figure 12
Lateral mixing of ice by the Finnish icebreaker Fennica using azimuthing thrusters to clear a channel. *Photo: Aker Finnyards*

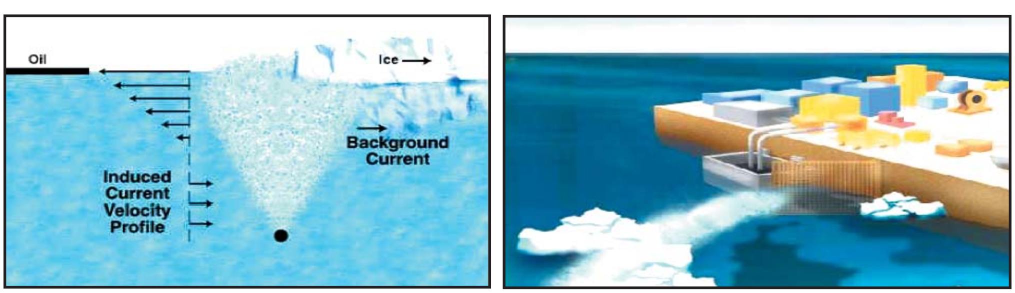

Figure 13 Conceptual sketches of pneumatic diversion boom in operation. *(ExxonMobil)*

All Figures referred to in the main text are located on these two pages. The following is a quick guide for finding the page on which each Figure is mentioned.

PRINCE WILLIAM SOUND OIL SPILL RECOVERY INSTITUTE

UNITED STATES ARCTIC RESEARCH COMMISSION

REMOTE SENSING OF OIL UNDER, IN, AMONG OR ON TOP OF ICE	
Need	It is essential to know where the oil is in order to plan a response. Urgent need is to be able to detect and locate, map the contamination boundaries, and track and monitor oil trapped with ice. **Fig. 1 (page 6).**
Baseline Knowledge	Substantial—Some success has been achieved in the past with acoustic technologies (Fingas and Brown 2002). Numerous projects have examined all possible technologies, but none has led to an operational system. Minerals Management Service (MMS) technology review covers experiences of past work (Dickins 2001). Recent progress includes testing a gas chromatograph/mass spectrometer (GCMS) for vapor extractions through ice in Alaska; and applying infra-red optical beam technologies to detect very low vapor concentrations, for example across a river (Alyeska Pipeline Service Co., unpublished). Current technology involves drilling large numbers of boreholes through the ice in a closely spaced pattern to uncover the presence of oil. Norwegian Clean Seas Association for Operating Companies (NOFO) has an ongoing program looking at advancing capabilities to detect oil for spill response in darkness. There are numerous examples where satellite imagery has been used to map oil slicks at sea, and radar satellites are routinely used to identify and map different ice types. However, the capabilities of space borne sensors to discriminate between oiled and clean ice, or to detect oil on relatively calm water between ice floes have not been investigated.
Political Sensitivity	None
Confidence	Low for aerial systems, increasing to medium for ground-based.
Timeline	2 years to demonstrate effectiveness of recent advances
Cost: Order of Magnitude	$100,000 per year to investigate ground-based systems. Aerial system development would be order(s) of magnitude more expensive with low chance of success.
Other Issues	
Example Projects	• Gas sniffing • Optical detectors • Evaluate proven open water sensors in a broken ice field (e.g. Infra-red,Laser Fluorosensor, and the latest generation of high resolution synthetic aperture radar (SAR) satellites)

TRANSFERRING VISCOUS PRODUCTS WITH ICE	
Need	Extend recent work on viscous oil pumping to understand the effect of ice pieces. Serious impact of slush and small ice chunks on ability to pump cold oily waste is a major problem.
Baseline Knowledge	Several recent projects by the U.S. Coast Guard (USCG) and Alaska Clean Seas (ACS) have focused on the problem of transferring cold oil products, including emulsions. There is no baseline knowledge in under standing how to pump oil and ice mixtures.
Political Sensitivity	None
Confidence	High
Timeline	1-2 years
Cost: Order of Magnitude	$100,000-$200,000
Other Issues	
Example Projects	• Processing viscous emulsions with small ice chunks. Integrated study encompassing all processing phases (collection, pumping, storage, offloading)

CHEMICAL HERDERS	
Need	Thicken slicks among broken ice floes so that the oil can be ignited and burned effectively. Equilibrium thickness of crude oil on cold water may not be sufficient to allow efficient in-situ burning in a natural state.
Baseline Knowledge	Some data for spills on open water. No data on behavior of herders in an ice environment. Initial lab-scale tests being carried out by ExxonMobil 2003.
Political Sensitivity	Reluctance to introduce another chemical into the environment may affect approvals, although herders typically have low toxicity and do not result in dispersion of oil into the water column.
Confidence	Moderate
Timeline	1 year for first phase
Cost: Order of Magnitude	$150,000 to fund full meso-scale program (cold basin) leading to possible future incorporation into field trials (Sec. 4.2)
Other Issues	The utility of chemical herders will depend upon approvals to conduct in-situ burning of the oil slick.
Example Projects	• Validate chemical herding action in ice. Primary purpose is to enhance in-situ burning by thickening oil.

ENHANCE CAPABILITIES OF EXISTING MECHANICAL RECOVERY SYSTEMS	
Need	Expand the operational capability of existing spill response equipment to enable oil recovery in ice. Examples: **Fig. 10 (page 7)**
Baseline Knowledge	Considerable background of testing different skimmer systems (oleophilic, brush, pumps, disks, weir) in ice, in tank tests, and full-scale applications. No recent attempts to optimize devices in freezing conditions with ice present.
Political Sensitivity	None. Mechanical systems are universally accepted.
Confidence	Low—improvements likely to be incremental, resulting in modest increase in recovery effectiveness. Critical problem with application of mechanical systems to deal with oil in ice is the low encounter rate (combination of small swath width and low speed of advance).
Timeline	1-2 years
Cost: Order of Magnitude	Not estimated
Other Issues	Need to employ standardized testing techniques to ensure that all parties, including citizens' advisory councils and regulatory agencies, accept comparative test results.
Example Projects	• Research to expand operating window for mechanical recovery with ice present could be linked to projects in oil deflection and herding, and may employ some aspect of ice management with support vessels. See preceding priority program descriptions.

SIMULANTS	
Need	Develop environmentally acceptable, surrogate oil for experiments and responder training in a realistic at-sea environment. Motivation is derived from inability to obtain permits to conduct field trials in U.S. waters with real oil.
Baseline Knowledge	Substantial previous efforts to identify a surrogate product, which mimics oil and poses no threat to the environment. Historical trials have included the use of oranges, popcorn, Hula Hoops and canola oil. Recent work at the University of Utah has led to some progress with an aerated, biological oil product, but the issue of stickiness remains unresolved.
Political Sensitivity	Significant—related to concerns about toxicity, solubility in water, and the impact on wildlife from stickiness.
Confidence	Low—improvements are likely to be incremental, resulting in a modest increase in recovery effectiveness.
Timeline	5 years
Cost: Order of Magnitude	Typical annual costs approximately $50,000 per year.
Other Issues	Potential for patents could interfere with joint funding.
Example Projects	• Develop surrogate oil, which is environmentally acceptable (low-toxicity, non-sticky, rapidly broken down) for experiments and responder training at sea.

4.2 Field Spills

The lack of any consistent regulatory framework to facilitate field trials with oil represents a critical obstacle to achieving real progress in the field of at-sea spill response. Most significant technical advances in Arctic spill response can be attributed to a series of highly successful field trials with oil carried out in U.S., Canadian and Norwegian waters. Many of these trials have involved moderate-size releases at an affordable cost.

Regular full-scale field trials with oil are essential to: (1) Validate and prove response technologies and strategies developed in laboratory or meso-scale tests; (2) Understand the fate and behavior of oil under different marine conditions; (3) Train and drill responders with real oil (in the same way that firefighters develop and maintain proficiency by practicing on real fires); (4) Develop operational guidelines for particular technologies; and, (5) Build confidence and trust among all of the stakeholders in oil spill response (public, industry and government). There is a particular need for further tests in dynamic pack ice. There have only been two field trials in pack (broken) ice: Canada in 1986 and Norway in 1993.

Spill responders need to know the strengths and shortcomings of all tools and techniques, based on full-scale, realistic experiences with oil. For example, the development of proven offshore spill response equipment has benefited greatly from lessons learned during annual exercises held in offshore Norway with spills of 100 tons of oil and emulsion. Experience has shown repeatedly that it is not feasible to rely on actual spills as an opportunity to collect useful scientific data sets in the absence of proper controls.

Field trials with oil can be designed as comprehensive international programs that integrate many complementary scientific, engineering and operational elements. Such trials can be carried out safely and in an environmentally responsible manner with a high degree of confidence, through a rigorous process of program design and execution. Key points regarding the near-term possibilities for new field trials with oil include:

- Permits, achievable in Canada and Norway, are considered highly unlikely in the United States based on negative outcomes with applications during the last 10 years—no spills in U.S. waters for experimental purposes have been allowed for nearly two decades. It is important to note that countries that have allowed field trials with oil have become leaders in spill research.
- Field trials are an essential element in validating and developing a broad range of complementary research and applied technologies.

The first stage in launching a new trial with oil in pack (broken) ice (considered the priority area) will involve a planning workshop to bring together all interested parties and stakeholders. Joint international funding will be essential to the success of any such trial (Sec. 4.4).

4.3 Important R&D Programs

The following ideas also need to be considered, in developing an overall research and development strategy (viewed in conjunction with the high priority programs selected in Sec. 4.1).

Title	Idea in Brief	Comments	Baseline
Rationalize Response Strategies	Develop an international set of performance-based standards governing systems and techniques for spill response in ice using organizations such as the American Society for Testing & Materials (ASTM) and the International Standards Organization (ISO).	Difficult to achieve given the widely different regulatory jurisdictions and national interests. Benefit would be consistent standards in spill response practices.	Example—Baltic states working to integrate response resources and strategies.
Net Environmental Benefit Analysis (NEBA)	Apply Net Environmental Benefit Analysis to strategies in ice for specific scenarios.	Results could provide valuable perspective on relative merits of different approaches (e.g. burning vs. mechanical)	In regular use to evaluate open water scenarios, though not yet being applied to oil and ice.
Realistic Scenarios	Develop realistic scenarios to evaluate and compare response options in a wide range of ice conditions.	"Real world" comparisons of response tools could help to modify regulatory approach to recommended strategies, and identify the most effective strategies in a given situation.	Industry projects on the North Slope and in Cook Inlet, though not generally public.
Risk Analysis	Conduct risk analysis of spill scenarios.	In theory, this type of analysis can help identify priority oil-in-ice scenarios. In reality, industry is often constrained by regulatory requirements to prepare for worst-case events, limiting the practical application of risk-based decision-making.	There are numerous worldwide examples of risk analysis during the development phase of projects (Environmental Assessment process).
Lessons from Past Spills	Reevaluate past spills in ice in terms of response operations (already done in terms of oil fate and behavior).	There is the opportunity to consolidate lessons learned, though much of the documentation is sparse and incomplete	Individual authors routinely conduct such evaluations reviews for specific projects.

Title	Idea in Brief	Comments	Baseline
Tank Tests	Develop controlled climate, tank facility for "realistic" tests.	Reliable meso- to full-scale testing with oil in ice requires reliable climate controls. There is a surplus of ice testing facilities worldwide, but few basins are willing to accept oil.	Tests with manufactured sea ice at Ohmsett (2002). Norway and Finland looking at funding new facilities.
Near shore Oil/Ice Interaction	Evaluate likely fate and behavior of oil trapped under bottom-fast in winter and on flooded ice in spring.	Issues include access over unstable flooded ice, responder safety, oil trapped between solid ices and frozen sediments, oil spreading on overflood waters.	No concerted effort to look at oil spill recovery under these conditions.
Shoreline Studies	Evaluate treatment options for oiled ice and ice rubble in the shoreline zone.	Could involve consideration of likely oil and ice interactions, focusing on means to access and remove the oil without waiting for spring melt. Tank testing could include the use of a simulated shoreline ice foot to study oil adhesion and removal.	Limited experience trying to remove oil spilled in grounded ice rubble. Little or no actual research has been done.
Monitoring and Tracking	Develop tools to account for a range of ice conditions in oil spill fate, behavior and tracking models.	Need for new analytical models to deal with oil and ice input data on a real-time basis. Prerequisite would be more reliable ice drift models as a starting point.	Little or no new work in past decade. Recent Minerals Management Service (MMS) initiatives in U.S.
Unstable Ice Logistics	Develop logistics options and vehicles to operate in the landfast zone during freeze-up and break-up	Focus on need for safe access to offshore sites when the ice is too thin, deteriorated, flooded or unstable for conventional surface vehicles.	Individual authors routinely conduct such evaluations reviews for specific projects.
Skimmer Evaluations	Compare effectiveness of different skimmer systems in ice using consistent methods.	Need to develop or use accepted test protocol to ensure agency acceptance.	Past work by Canadian Coast Guard and others.
Vessel Ice Management	Evaluate potential for icebreakers and other vessels to support and influence the outcome of a response operation in ice.	Exploit capabilities of new azimuthing drive icebreaker designs, and any other available support vessel, to aid in breaking down floe sizes, using prop washing to release trapped oil, and deflecting large floes. **Fig. 12 (page 7)**	Finnish concept studies include asymmetric hull forms to create open water areas. Routine operating technique in Cook Inlet.

4.4 Universal Research & Development Elements

Three all-encompassing ideas are identified as recommended elements to be considered in the development of any new oil-in-ice research and development program:

1) The need for more flexible regulations to facilitate the application of all possible response tools from the outset of a response. Regulations need to account for unique aspects of oil-in-ice response compared with open water. Examples include: natural containment offered by the ice, dramatically reduced spreading rates, and natural shore protection provided by the land-fast ice.
2) Development of long-term education and public outreach programs to explain the trade-offs, benefits and drawbacks of different response strategies.
3) Application of biological sciences as part of net environmental benefit analysis (NEBA) to assess the merits of different response strategies.

Field trials with oil are also identified as a universal element with broad applicability to a wide range of research and development programs. These trials are considered essential for advancing the knowledge base and capabilities for oil in ice response. Sec. 4.2 includes an expanded discussion of the benefits and rationale for future trials.

4.4 Avenues for Funding

A carefully focused work plan or agenda encompassing a short list of priority projects is generally beyond the capabilities of any one organization to fund in its entirety. International cooperation, including government and industry participants, is needed to make substantial progress in the most important research and development areas.

Given the specialized nature and limited number of researchers actively working in the area of oil-in-ice spill response, it is essential to involve different centers of expertise on a global level. The following list represents examples of government institutes, agencies and organizations worldwide that are currently involved in Arctic spill research. This list is not intended to be all-inclusive and does not include private consulting groups:

- Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, Alaska
- Cooperative Institute for Coastal and Estuarine Technology (CICEET), a joint venture between the University of New Hampshire and the National Oceanic and Atmospheric Administration (NOAA)
- Alaska Department of Environmental Conservation—Charter agreement between with BP Exploration (Alaska) and ConocoPhillips
- US Department of Interior, Minerals Management Service (MMS), Engineering and Research Branch, Herndon, Virginia
- Fisheries and Oceans Canada—Centre for Offshore Oil and Gas Environmental Research (COOGER), Dartmouth, Nova Scotia, Canada
- Finnish Environment Institute in conjunction with VTT Technical Research Centre of Finland
- Arctic Council Working Group on Emergency, Prevention, Preparedness and Response (EPPR)
- Baltic Marine Environment Protection Commission—Helsinki Commission (HELCOM)
- International Navigation Association (PIANC), Maritime Navigation Commission
- Norwegian Clean Seas Association for Operating Companies (NOFO)
- Alaska Clean Seas (ACS), Prudhoe Bay, Alaska (oil spill cooperative)

Future developments in the Arctic oil spill response field will likely involve cooperative funding by government agencies and operators. Multi-national corporations involved in oil development in regions such as Sakhalin Island, the Siberian Arctic, the Caspian Sea, and Alaska have a strong interest in pursuing research in this field. A number of these companies are likely to become participants in any major new research and development initiative aimed at improving their capabilities to respond to spills in remote ice-covered areas (e.g. AgipKCO, ExxonMobil, BP, Sakhalin Energy Investment Company, Statoil, ConocoPhillips).

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APPENDICES

Appendix A

Project Steering Committee (2003)

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Appendix B

Solicitation for Technical Comments on Initial Draft (October 2003)

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- BP Exploration (Alaska)
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- Cook Inlet Spill Prevention and Response
- Alaska Clean Seas
- US Navy Supervisor of Salvage and Diving (SUPSALV)
- Alyeska (SERVS)
- Cook Inlet Regional Citizens Advisory Council
- US Arctic Research Commission
- NOAA Hazmat
- ExxonMobil Upstream Research Company
- State of Alaska Department of Environmental Conservation
- Cook Inlet Spill Prevention and Response Inc.
- Polaris Applied Sciences Inc.
- US Coast Guard R&D Center
- Spiltec
- Clean Caribbean (Antarctic)
- University of New Hampshire

FINLAND

- Finnish Environment Institute
- VTT Technical Research Centre of Finland, Helsinki
- Aker Finyards

NORWAY

- Norwegian Pollution Control Authority
- Norwegian Clean Seas Association for Operating Companies (NOFO)
- Sintef
- University Svalbard

CANADA

- Environment Canada
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- Innovative Ventures
- SL Ross Environmental Research Limited

RUSSIAN FEDERATION

- Central Marine Research and Design Institute - CNIIMF
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Appendix C

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ADVANCING OIL SPILL RESPONSE

IN ICE-COVERED WATERS

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