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Advancing Oil Spill Response in Ice-Covered Waters: an R&D Agenda

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Abstract
The paper presents the results from a two-year project to identify areas where further research and development will improve the ability of responders to deal with an accidental oil spill into a marine environment (fresh or salt water) in the presence of ice. The subject of oil spills in ice is of concern to corporations, local residents, and government agencies participating in oil exploration, production and/or transportation in such diverse areas as: Sakhalin Island, Norwegian Barents Sea, Baltic Sea, Cook Inlet and the North Slope, Alaska and the Caspian Sea. As reserves are depleted in more readily accessible areas, exploration and production activities will increase in arctic frontier regions. It is hoped that this project will lead to the development of more capable prevention and response strategies for oil spills in ice-covered waters.

Some sixty potential research and development ideas were initially derived from the proceedings of the 2000 Oil and Ice conference held in Anchorage. These ideas were screened and assessed through a process of expert reviews, public comment and a two-day workshop. Examples of priority program areas identified in this project include: detection of oil in ice, dispersants in ice, oil deflection, chemical herders in ice, oil simulants to allow more frequent field trials, and transfer of viscous oily waste under freezing conditions. The project also highlighted the need for progress on non R&D issues such as training, public education and development of realistic regulations and standards. Field spills with oil are identified as critical to improving spill response capabilities under all marine conditions (ice and open water).

Introduction

Following the International Oil and Ice Workshop (Alaska Clean Seas, 2000), the Prince William Sound Oil Spill Recovery Institute (OSRI) funded grant applications in 2001 and 2003 by DF Dickins Associates Ltd. to identify critical deficiencies in the current state of knowledge with regard to oil spills in any form of ice. The study findings were published for international distribution under the joint sponsorship of OSRI and the United States Arctic Research Commission (Dickins, 2004).

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. 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 U.S. Arctic Research Commission was established by the Arctic Research and Policy Act of 1984 (as amended in November 1990). The Commission assesses national needs for Arctic research and recommends research policies and priorities that form the basis for a US national Arctic research plan. 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 arctic oil spill response strategies. Greater marine access anticipated 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.

Goals and Objectives
The overall objective of this project is to identify programs and related research and development projects, which could improve the ability of responders to deal with an accidental oil spill into a marine environment (fresh or salt water) 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 (landfast), into an area of drifting ice floes (pack ice), or onto an ice covered shoreline.

The subject of oil spills in ice is of concern to corporations, local residents, and government agencies participating in oil exploration, production and/or transportation in areas such as Cook Inlet, Beaufort Sea (including the North Slope of Alaska), offshore Sakhalin Island, Norwegian Barents Sea, Baltic Sea and the Caspian Sea. As reserves are depleted in more readily accessible areas, cold frontier regions will receive continuing attention in terms of exploration and production.

The greatest need in most areas of the world is to develop a credible and effective response to oil 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 detect or map oil in any ice type.

Background
The subject of oil spills in ice has received a great deal of attention over the past 30 years. Dickins and Buist (1999) provide a brief summary of work in this field. Additional reference sources include annual proceedings published by Environment Canada on the AMOP series of conferences (1977 to date), the International Oil and Ice Workshop (Anchorage, April 2000), and a specialized Seminar on Marine Oil Spills in Ice, sponsored by the Finnish Environment Institute (Helsinki, November 2001).

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 tests (meso-scale) and full-scale field trials. Figures 1 and 2 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; Mullin et al., 2003), and in-situ burning in slush and brash ice in the Alaska Clean Seas wave tank at Prudhoe Bay (Buist et al., 2003).

Figure 1

Figure 2

Many significant technical advances in arctic spill response can be attributed to a series of successful field trials with oil carried out in US, Canadian and Norwegian waters over the past 30 years. Figure 3 shows one of these projects involving crude oil in pack ice off the Canadian East Coast in 1986 (SL Ross and DF Dickins, 1987). A second spill in broken ice was carried out off Norway in 1993 (Vefsnmo and Johannessen, 1994).

Figure 3

Two successful oil spill research projects in the Canadian Beaufort Sea (Norcor 1975, Dickins and Buist 1981) contributed to *in situ* burning becoming accepted as a primary Arctic response strategy to deal with spills in ice (Fig. 4).

Figure 4

Mechanical recovery is a practical and effective strategy in solid, fast ice (Allen and Nelson, 1981; Alaska Clean Seas 1999). However, field demonstrations have shown that conventional mechanical containment and recovery systems have serious limitations in broken or unstable ice (Bronson et al., 2002). Mechanical equipment (E.g., rope-mops, brush skimmers) can be used to recover small, isolated patches of oil in broken ice. Figure 5 shows a rope-mop skimmer being deployed from a barge during trials off the North Slope of Alaska.

Figure 5

International efforts to develop dedicated mechanical systems for natural broken ice operations have not yet progressed beyond the prototype stage (Mullin et al., 2003). Finland has successfully developed full-scale operational systems to deal with relatively small ice piece sizes in Baltic shipping channels (Rytkonen et al., 2003).

In the past, limited consideration has been given to the use of dispersants for spills in ice. Brown and Goodman (1996) and Ross (2000) summarize previous experience. There has been recent progress in this area; tests at the Ohmsett facility in 2002 showed greater than 90% dispersion with fresh crude oil spilled into broken ice in the presence of waves (Owens and Belore, 2004). These results are leading to a re-appraisal of dispersant potential under Arctic offshore conditions.

Methods

This project started with over 60 ideas and research concepts derived principally from presentations made at the International Oil & Ice Workshop (ACS 2000). This initial list was screened to create a subset of ideas subjectively determined to have moderate or high potential to improve response effectiveness. The second and final Phase of the project began in the spring of 2003, with the aim of recommending research and development programs and projects to improve future response capabilities. A transparent process of consultation was created to ensure the maximum opportunity for comment and input from a wide range of interested parties. This process involved:

- Appointing a steering committee to help define the scope of the project,
- 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,
- Posting a synopsis of research ideas on two web sites for public review and comment (OSRI and "Arctic Info" maintained by the Arctic Research Consortium of the United States (ARCUS), and
- Holding a two-day workshop in Anchorage (November 4-5, 2003) with a small group of invited specialists from government, industry and the consulting research community.

Workshop Process
A short list of high priority program areas (and associated projects) was developed at a two-day workshop in Anchorage. Participants representing a broad range of interests and applied experience were drawn from government regulatory agencies, oil industry, oil spill response cooperatives and the consulting research community (Acknowledgements).

The workshop was used as a vehicle, to screen ideas, to develop some broad parameters for specific programs and to identify examples of specific projects. The following questions were posed as general criteria to help participants consider different ideas:

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 (a related question would be to consider whether research in this area is likely to yield positive results)?

Seven priority program areas were selected at the workshop: Dispersants in Ice, Oil Deflection, Detection of Oil in Ice (Remote Sensing), Transfer of Icy, Oily Waste, Chemical Herders, Enhancements to Capabilities of Existing Mechanical Systems, and Simulants. Each of these areas is described in more detail below. Participants at the workshop considered burning oil in ice to be sufficiently well understood that substantial new research was not considered a high priority. It is important to recognize that no one grouping of individuals can provide the final word on merit or value. Consequently, other important ideas were retained (tabled below).

Results and Recommendations
This section further develops the scope of the seven ideas selected as priority R&D programs, and briefly describes other important ideas identified during the project.

Overview of Priority R&D Areas
Largely as a result of a series of successful arctic field experiments in the 1970's and early 80's, in situ burning has become accepted as the most effective oil recovery strategy in many situations involving spills into ice covered waters. There is an extensive body of knowledge on the fundamentals of how and when burning can be used in different ice types.

New research and development in this area needs to concentrate on measures or techniques to expand the already proven and demonstrated operating window for burning in ice, for example in situations involving thin films among ice floes. The successful development of chemical herders could enhance burning in these marginal situations.

The effectiveness of mechanical recovery of oil spilled in pack ice is limited by the problem of drifting ice interrupting conventional containment and skimming activities. Further work to enhance the ability of existing mechanical equipment to operate in ice is considered worthwhile, but unlikely to produce substantial gains in response effectiveness. New techniques to deflect oil and/or separate oil and ice using for example, 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, complementing and supporting other techniques. The use of dispersants in cold-water environments with ice has been viewed as having a low potential for success. Key concerns have centered on the lack of natural mixing energy due to the damping effects of the ice, and the tendency for oils to become viscous at low temperatures. Recent promising results in industry-sponsored tank tests have spurred a reexamination of dispersants as a potential strategy for certain oil-in-ice situations. The use of icebreakers or other vessels to introduce the necessary mixing energy (Fig. 6), 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 at an early stage, and much more work needs to be done before a definitive answer is available.

Figure 6

Detecting and mapping oil trapped in, under, on or among ice remains a critical deficiency, affecting all aspects of response to spills in ice. In spite of considerable past effort, their is still no practical operational system to detect or map oil. Although previous technologies have not evolved into operational systems, there are a number of avenues where further research into ground-based remote sensing could yield major benefits. Examples include recent tests with optical beams and consideration of hydrocarbon "sniffer" technologies. However, the ultimate goal of aerial remote sensing to detect oil in ice remains as elusive as ever.

The transfer of oily waste under freezing temperatures with a mix of small ice chunks and/or slush 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.

The lack of readily available permits to conduct field spills in many parts of the world remains a serious drawback to developing more effective arctic spill response techniques. Simulants have been considered in the past as a means of facilitating permits and allowing realistic field trials. At present, there is no product, which will mimic real oil without any environmental impact. Work is continuing in this area, motivated by the need to test personnel and equipment in a realistic setting.

Further details of each priority program area are provided below.

Selected Priority Program Areas with 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.
Baseline Knowledge	There have been some tests conducted in cold water and limited tank/basin tests in broken ice (Brown and Goodman, 1996 and Owens and Belore, 2004). ExxonMobil is currently looking at the possibilities for dispersant mixing with icebreakers and formulating/testing a new dispersant for viscous oils.
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.
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 (Georges-Ares et. al., 2001)

Example Projects	• Mixing with icebreakers (or other vessels) - Figure 6 • Developing a dispersant for viscous (cold) oils • Evaluating potential for long-term retention (for example, 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/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 would ideally direct oil to a collection/recovery area while moving the ice in another direction or leaving it behind.
Baseline Knowledge	<u>Limited</u> (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 terminal (tried also in Cook Inlet). Initial feasibility of pneumatic diversion booms was evaluated at lab scale by ExxonMobil in 2003 (unpublished). A series of projects are planned to further develop this concept in 2004 and 2005.
Political Sensitivity	<u>None</u> - mechanical recovery methods are accepted in all jurisdictions.
Confidence	<u>Medium.</u> Major constraint centers on the difficulty of moving oil a significant distance (beyond 20 to 30 m).
Other Issues	May have applications for improved containment and recovery in non-ice areas such as rivers and streams. The ability of modern icebreakers to influence the surrounding ice over distances several times the vessel's beam could be valuable - Fig. 6
Example Projects	• Propeller wash • Pneumatic diversion booms (the idea being to divert oil while letting ice pass) • Air jet blowers

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 (locate), map the contamination boundaries, track and monitor oil trapped with ice.
Baseline Knowledge	Substantial. Some success achieved in past with acoustic technologies (Fingas and Brown 2002). Numerous projects have examined possible technologies but none has led to an operational system. MMS technology review covered experiences of past work (Dickins 2000). Recent (2003) developments include considering the possibility of using hydrocarbon gas detectors to identify low-level concentrations above an ice sheet and applying I/R optical beam technologies to detect very low vapor concentrations across a river (Alyeska - unpublished). Current relatively crude technology involves drilling large numbers of boreholes through the ice to uncover the presence of oil. Satellite imagery is used to map oil slicks at sea, and 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 are thought to be limited (data lacking).
Political Sensitivity	None
Confidence	Low for aerial systems, increasing to medium for ground-based. Relatively high research risk is balanced by the critical need for a solution.
Example Projects	• Hydrocarbon "sniffers" - Geochemical methods • Optical detectors • Evaluate capabilities of open water sensors in a broken ice field (e.g., I/R, Laser Fluorosensor, and the latest generation of high resolution SAR radar satellites)

TRANSFERRING VISCOUS PRODUCTS WITH ICE	
Need	Extend recent work on viscous oil pumping to understand the effect of ice pieces. Slush and small ice chunks will seriously degrade the pumping of cold oily waste.
Baseline Knowledge	Several recent projects by the USCG and Alaska Clean Seas have focused on the problem of transferring cold oil products, including emulsions. There is no baseline of knowledge in understanding how to pump oil and ice mixtures.
Political Sensitivity	None
Confidence	High
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 more effectively.
Baseline Knowledge	Some data in open water, none in an ice environment. Initial lab-scale tests by ExxonMobil in 2003 (unpublished).
Political Sensitivity	Reluctance to introduce another chemical into the environment may affect approvals. Note: herders typically have low toxicity and do not result in dispersion of oil into the water column.
Confidence	Moderate
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 EXISTING MECHANICAL RECOVERY SYSTEMS	
Need	Expand the operating envelope of existing spill response equipment to enable oil recovery in ice. (E.g. Fig. 5)
Baseline Knowledge	Considerable background of testing different skimmer systems 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	<u>Low</u> - improvements likely to be incremental, resulting in modest increase in recovery effectiveness. Critical problem with mechanical systems in ice is the very low encounter rate.
Other Issues	Need to employ standardized testing techniques to ensure that comparative test results are broadly accepted.
Example Projects	• Research to expand operating window for mechanical recovery in ice could be linked to projects in oil deflection and herding with ice management from support vessels.
SIMULANTS	
Need	Develop environmentally acceptable, surrogate oil (thereby simplifying the often complex permit process)
Baseline Knowledge	Substantial previous efforts to identify a surrogate product, which mimics oil and poses no threat to the environment. Recent work at the University of Utah (unpublished) has led to some progress with an aerated, biological oil product (stickiness is still an issue).
Political Sensitivity	<u>Significant</u> - related to concerns about toxicity, solubility in water and impact on wildlife (smothering).
Confidence	<u>Low</u> - improvements are likely to be incremental, resulting in a modest increase in recovery effectiveness.
Other Issues	Potential for patents could interfere with joint funding.
Example Projects	• Develop surrogate oil, which is environmentally acceptable for experiments and responder training at sea.

Important R&D Programs

The following ideas were also identified through the course of the project.

Title	Idea in Brief	Comments
Rationalize Response Strategies	Develop an international set of performance-based standards governing systems and strategies for spill response in ice.	Difficult to achieve given the widely different regulatory jurisdictions and national interests. Benefit would be more consistent standards in spill response practices. (E.g., agreements between neighboring countries in the Baltic, and recent moves by ISO and IMO towards perfomance-based standards.)
Net Environmental Benefit Analysis (NEBA)	Apply NEBA to strategies in ice for specific scenarios.	Results could provide valuable perspective on relative merits of different approaches (e.g., burning vs. mechanical). Commonly applied to open water scenarios.
Realistic Scenarios	Develop realistic scenarios for response in ice.	"Real world" comparisons of response tools may help modify regulatory approaches to recommended strategies, and identify the most effective strategies in a given situation.
Risk Analysis	Risk analysis of spill scenarios	In theory, this type of analysis can help to set priorities for spill response. In reality, industry is often mandated by law to prepare for worst-case events regardless of absolute risk.
Lessons from Past Spills	Revisit past spills in ice in terms of response operations.	Opportunity to consolidate lessons learned. Drawback - much of the required documentation is sparse and incomplete.
Tank Tests	Develop controlled climate, tank facility for "realistic" tests.	Reliable meso-scale testing with oil in ice requires reliable climate controls. Few ice test basins accept crude oil.
Nearshore Oil/Ice Interaction	Evaluate likely fate/behavior of oil under bottom-fast in winter and/or on flooded ice in spring.	Issues include access over unstable flooded ice, responder safety, oil trapped between solid ice and frozen sediments, oil spreading on overflood waters. These topics have not been investigated in any detail.

Title	Idea in Brief	Comments
Shoreline Studies	Evaluate treatment options for oiled ice and ice rubble in the 'shoreline zone'.	Could involve likely oil/ice interactions, focusing on means to access and remove the oil without waiting for spring melt. Tank tests could simulate a shoreline ice foot to study oil adhesion and removal.
Monitoring and Tracking	Develop tools to account for a range of ice conditions in new 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.
Unstable Ice Logistics	Develop logistics options for 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.
Vessel Ice Management	Evaluate potential for icebreakers and other vessels to support a response operation in ice.	Exploit capabilities of new azimuthing drive icebreaker designs (e.g. Fig. 6) to break down floes, release trapped oil, deflect large floes etc. Recent Finnish concepts include ice-breaking vessels with asymmetric hull forms.

Field Spills

The lack of any consistent regulatory framework to facilitate field trials with oil represents a critical impediment to achieving real progress in the field of at-sea spill response. Over the past twenty years, many significant technical advances in arctic spill response can be attributed to a series of highly successful field trials with oil carried out in Canadian and Norwegian waters. There is a particular need for further tests in dynamic pack ice (only two such trials were conducted).

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 spill responders with real, and (4) develop operational guidelines for particular technologies.

Experience has shown that field trials with oil can be carried out safely and in an environmentally responsible manner with a high degree of confidence. Permits, possible in Canada and Norway, are considered highly unlikely to be granted in the United States (no spills in US waters for experimental purposes have been allowed for nearly two decades). It is important to note that countries such as Norway that have allowed field trials with oil have become leaders in spill research.

Universal R&D Elements

Three all-encompassing ideas are identified as recommended elements in the development of future oil-in-ice research and development programs:

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 areas of contamination, and natural shore protection provided by 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.

Avenues for Funding

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, Siberian Arctic, 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 R&D initiative aimed at improving their capabilities to respond to spills in remote ice covered 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 international centers of expertise (E.g., Canada, Norway, Finland, US, Russian Federation).

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Captions

Figure 1 Manufactured ice field used for MORICE tests at the Ohmsett test tank, January 2002 (Buist and Dickins, 2002)

Figure 2 Burning in brash ice, ACS wave tank at Prudhoe Bay AK, October 2002 (Buist et al., 2003)

Figure 3 Oil in slush among pancake ice off the Canadian East Coast, 1986 (SL Ross and DF Dickins, 1987)

Figure 4 Burning crude oil in slush filled lead off Nova Scotia, Canada 1986 (SL Ross and DF Dickins, 1987)

Figure 5 Rope-mop skimmer in ice (Photo: Alaska Clean Seas)

Figure 6 Lateral mixing of ice by the Finnish icebreaker *Fennica* using azimuthing thrustors to clear a channel (Photo: Aker Finnyards)