Summary Report:
Workshop to Determine the Scope of an Experimental Oil Spill in Pack Ice

Prepared for:

United States Department of the Interior
Minerals Management Service
Herndon, VA

Department of Fisheries and Oceans
Centre for Offshore Oil and Gas Environmental Research
Dartmouth, NS

Prepared by:

SL Ross Environmental Research Limited
Ottawa, ON

and

DF Dickins Associates Ltd.
La Jolla, CA

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Introduction

This report summarizes the proceedings of a planning workshop on the subject of an experimental oil spill in pack ice. The workshop was co-sponsored by the U.S. Minerals Management Service (MMS) and the Canadian Department of Fisheries and Oceans (DFO), and was held on November 1 and 2, 2005 in Dartmouth, Nova Scotia. The sponsors sought to bring together a number of parties and stakeholders interested in participating in such an experimental oil spill.

The objective of the workshop was to identify research and development priorities and to establish a framework that would lead to an international program of experimental spills in pack ice.

The rationale for planning a large-scale experimental spill is that the current basis for "Best Practices" in this field is largely based on only two field experiments, which occurred 12 and 19 years ago, respectively. There is a definite need to collect basic scientific data on the behavior and fate of oil in a variety of pack ice conditions, and to test a variety of existing and evolving response strategies for use in ice-affected waters.

Small and meso-scale tank scale tests have been effective for investigating new technologies and equipment for use in pack ice. However there are serious limitations in scaling to an open ocean pack environment. At some stage, in order to build confidence and confirm that strategies will actually work in the "real world" there is no substitute for a full-scale field spill. Field trials are essential to not only validate technologies and improve our basic scientific understanding but also to provide a rare opportunity to train and educate responders and stakeholders in a realistic setting.

There is an obvious and increasing interest in preparing for spills in pack ice conditions, related to the increasing levels of offshore development activity and shipping activity in frontier areas. As further impetus for planning a spill at this time, the upcoming International Polar Year (IPY, years 2007 through 2011 in Canada) provides an opportunity to access significant levels of funding and logistical marine support for an experimental spill focused on science.

Background

In preparation for the workshop, invitations were sent to individuals and organizations in government, industry, and academe. The emphasis was on individuals who had experience in research and development of spill behavior and countermeasures in Arctic environments, either as primary researchers or as funders of such research. A list of attendees and contact information is presented in Appendix A.

A draft agenda and background information document (Appendix B) were also prepared and circulated for comment.

The background document provides an introduction to the subject of oil spills in ice. It was intended to provide a focus for workshop discussions, and to ensure a common starting point in terms of "what has been done" and "what needs to be done" in the five main subject areas of spill behavior, detection and tracking, mechanical recovery, in situ burning, and dispersant use. Specifically, the background document covers:

- The state-of-the-art and major knowledge gaps in oil spill behavior and potential response tactics in a pack ice environment;
- The history of experimental spills in pack ice focusing on the two previous large-scale field projects (1986 and 93); and
- Possible improvements in knowledge or technology that could be realized by re-examining response tactics in a full-scale ice environment.

Summary of Workshop

The following is not intended as a verbatim transcript of the workshop proceedings, but rather as a summary of the key points that were discussed, and the consensus that was reached on key issues. The agenda that was followed for the workshop is included as Appendix C.

Presentations

After introductory remarks and welcomes, a series of presentations were made, with a focus on recent experiments, field trials, and advances in spill behavior and countermeasures in an ice environment. These are briefly summarized below.

Past experimental spills and workshops
(David Dickins, DF Dickins Associates)

- Reference to previous experimental spills in ice and/or Arctic (Canadian and American Beaufort, 1972 to 1981; Baffin Island, 1981; experimental spills in pack ice in Canada – 1986, Norway 1993; accidental spills in ice: Buzzards Bay*, Kurdistan, Antonio Gramsci.*
- tank/basin tests: Esso Basin Calgary, Ohmsett NJ, CRREL NH, HSVA Hamburg, NRC Ottawa, ACS Wave Tank Prudhoe Bay, SL Ross lab facility Ottawa).
- Summary of Canadian oil in pack ice experiment (Ross and Dickins 1986) and Norwegian experiment (SINTEF 1993).
- Reference to previous related workshops (Anchorage 2001; Anchorage 2003).
- Key workshop finding: importance of experimental spills to validate lab- and meso-scale findings.

Recent developments in the Baltic Region, tests with ice cleaners and skimmers
(Kari Lampela, Finnish Environmental Institute)

- Field trials of vibrating oil-in-ice skimmer evolved from the original "Ice Cleaner" tests in 1983/85 (used ~ 8 times on real spills)
- Need to test present generation of Baltic mechanical recovery systems in full-scale ice field with representative "thick" ice.
- Tank tests of azimuth drive icebreaker (2002) re: spill response with over-the-side skimmers.
- New multi-purpose icebreaker being built in Finland for end of 2007 delivery, incorporating the vibrating skimmer unit. Eventually will have three vessels equipped with these systems in Finland and one in Estonia.
- Regulations are changing with respect to burning as an accepted alternative to mechanical recovery in the Baltic (limited previous experience).

Alaskan regulatory experience, containment & recovery experiments in ice
(Lee Majors, Alaska Clean Seas)

- Development of tactics manual to support North Slope (Alaska) operators.
- Tactics identified for various spill situations, including spills on, under, and among ice.
- Field trials in 2000 demonstrated limitations of containment with large boom systems in recovery techniques in anything but trace ice conditions.
- Shift in strategy to use of smaller over-the-side systems to maneuver among ice.
- ISB cannot be included directly in contingency plans but it is still considered an approved alternative on the North Slope.
- Tank on North Slope used for various experiments, including meso-scale burning, burning in ice.
- Support for other oil-in-ice projects: herders, dispersant use, use of emulsion breakers, oil-in-ice detection.
- Multi-year effort on various aspects of pumping viscous oils and emulsions.
- Priorities for the future include: continuation of above; tactics for shallow water, tactics for overflood conditions (2005 testing included concepts of mechanical recovery and temporary storage in bladders left on the melting ice).

Update on recent research and priorities for the future
(Ivar Singsaas, SINTEF)

- Summary of ongoing Arctic Operational Platform (ARCOP) projects for EU, re: Arctic-shipping risks. http://www.arcop.fi
- Discussed issue of water uptake as a function of ice concentration and influence on burn potential. Pictures of a temporary flume cut into fast ice on Svalbard.
- Photos of new oil/ice basin incorporated in Trondheim research facility (with major contribution from Statoil).
- Summary of the state-of-the-art in oil-in-ice behavior and response: ongoing effort to translate body of literature (USA, Canada, Norway, Finland, Russia) into English.
- Mentioned series of small releases at the ice edge for training students at UNIS (not documented or published).

- Use of NEBA modeling tools to help overcome perceived risks vs. scientific evidence.
- Pre-JIP (O ct 05 to Jan 06) with five participants (ConocoPhilips, Chevron Texaco, Statoil, Shell, Total) to look at possible program including four experimental spills in the 2006-09 time frame. Draft program description to finish by Dec 05 followed by 1-day workshop in Jan 06. Results likely to be public.

Summary of various MMS sponsored oil-in-ice projects
(Joe Mullin, MMS)
- Review of Ohmsett capabilities.
- Ability to test at full-scale in ice, cold-water.
- Use of Ohmsett for MORICE (oil-in-ice skimmer) tests, cold-water dispersant use, dispersant use in ice, upcoming herders in ice experiment.
- Review of other relevant MMS-sponsored research.

Oil Mineral Aggregate (OMA) research
Ken Lee, Department of Fisheries and Oceans
- History of OMA concept, starting with observations post *Exxon Valdez*.
- Experiments in sediment relocation and surf washing.
- Observations of OMA benefit during oil-in-ice spill in St. Lawrence River.
- Looking at options to apply OMA to spills on the ice such as spreading dry fines and wet application with fire hoses.
- Overall aim of OMA is to reduce costs of clean up with a natural dispersant that overcomes many of the permitting obstacles faced by chemical dispersants.

Recent spills-in-ice research, including dispersant tests
Tim Nedwed, ExxonMobil Upstream Research Company
- Summary of ExxonMobil sponsored research.
- Focus on technologies applicable to large spills: ISB and dispersants
- Use of vessels to enhance post-application mixing of dispersants applied to oil in ice. Tank tests show potential to get 80% or more dispersant effectiveness even with very low dispersant to oil ratios and weathered slicks.
- Development of dispersant for viscous oils.
- Development of dispersant with extended contact time; apply dispersant to oil in a low-energy environment (oil on ice, among dense ice), effective later when energy increases.
- Use of herders to increase slick thickness among ice, to enhance in situ burning.

Oil-in-Ice Behavior; In situ burning in pack ice; recent tests with herding agents
Ian Buist, SL Ross Environmental Research Limited
- Brief summary of SLRoss work on oil-in-ice weathering experiments, 2004 to 2007.
- Refinement of weathering algorithms and modeling of spreading, evaporative loss, emulsification of oil in the presence of ice and snow.
- Tests in SLRoss lab and meso-scale tank in Alaska to determine the limits of burning in slush and brash ice.

- Determined guidelines for minimum ignitable thickness, burn efficiency, and extinction thickness for various ice conditions.
- Summary of lab tests (2004) and meso- and full-scale tank tests (2005, 2006) to determine effectiveness of chemical herders to concentrate thin slicks for the purposes of in situ burning.
- Concept promising for increasing slick thickness from 1 mm to ignitable range of 2 to 3 mm, in presence of ice pieces. Potential to achieve oil removal % as good as with a fireboom by using herders in light ice conditions.
- Herder wind threshold of 3 knots only an issue if you are trying to thicken oil against a fixed boundary – not an issue with drifting ice in a free field conditions.

Recent developments with detection of oil in ice
David Dickins, DF Dickins Associates Ltd.

- Review of technology (2000) and testing (2004, 2005) to determine best technologies for detecting oil under ice. Surface-based GPR systems successful in detecting 2-3 cm oil films under 40 cm of solid ice in the CRREL tank. Field trials without oil at Prudhoe Bay in April 2005 demonstrated radar system reliability at –20°C and ability to profile up to 2 m of first-year ice at frequencies that will still allow discrimination of oil films ~5 cm under the ice.
- Most promise with two devices: ground-penetrating radar (GPR) and ethane sensor.
- Planning for Svalbard spill 3,800 liters, April 2006: airborne GPR, ethane flux, and acoustics – proposal under review by MMS, ADEC committed funds, + JIP
- Key issues to resolve: will flux levels through natural (as opposed to lab) ice be sufficient to allow airborne ethane sampling; difficulty of detecting oil in rough ice (rubble/rafting), ability of radar to differentiate oil that has diffused vertically through warm ice.

Participants' Expectations

As part of the discussions, participants were surveyed as to their goals and expectations for the workshop. These are listed below:

- Establish a multi-year plan for a series of experimental spills.
- Assess needs for experimental spills.
- Validate promising lab and meso-scale test results with full-scale spills.
- Establish basis for international collaboration to maximize R&D effectiveness.
- Move science of oil spill response in ice forward.
- Study fate and effects of oil in open pack ice (2 to 7/10^{ths}).
- Collect better data to improve modeling of oil in ice.
- Bridge the gap between R&D and operations.
- Determine best practices with current technology for oil in ice response
- Understand operating limits (aka windows of opportunity) associated with each response strategy.
- Need to assess threats as a basis for setting R&D priorities.
- Develop new spill response tactics.

- Develop response tactics for increased risks, re: increased Baltic transportation, exploration and production in frontier areas.
- Refresh/confirm/improve existing tactics and equipment.
- Test current generation mechanical systems at full scale.
- Link R&D to short and long-term needs with respect to proposed developments.
- Improve response in broken ice in shallow waters.

Potential research topics

This portion of the workshop involved an open discussion of potential research topics for each of the main subject areas: spill behavior, detection and tracking, mechanical recovery, in situ burning, and dispersant use. The idea was to list all potential projects of interest, while focusing on concepts:

- That have shown promise at small- or mid-scale, and
- That could benefit from re-examination or testing in a full-scale ice environment.

At the conclusion of the discussion, the proposed topics were ranked according to their perceived priority, based on the likely chances of success and potential benefits of the concept. The proposed research topics are listed below, with lower priority ones shown at the end of each list.

Following on earlier discussions regarding participant expectations, the group also addressed the spill scenarios that should be considered in the selection and design of any experiments. The main concern here was that the selection and design of experiments were not biased towards only one type or size of spill. It was agreed that the both batch-type releases and longer-term releases (i.e., blowouts) should be addressed; the main differences being total spill volume and initial slick thicknesses. It was also agreed that large spills, though rare, were still of concern from a research and planning perspective.

Similarly, for the scenario ice conditions, it was agreed that the significant differences between various ice parameters (e.g., floe size, concentration, presence of brash) be considered in the selection and design of experiments.

For the main scenario parameters, specifically the spill release conditions and ice conditions, no priorities were discussed as it was felt that all listed possibilities were of some concern to at least some of the stakeholders.

Potential Scenarios: Spill Release Conditions

- Tanker Releases
- Other Shipping Releases
- Sub-Sea pipelines (chronic/rupture/surface)
- Blowouts (surface/subsea)
- Tank/transfer failure shore-based

Potential Scenarios: Ice Conditions

- MIZ (marginal ice) – variable floe spectra, dynamic, ocean swell influence, higher energy
- Beaufort - shoulder seasons (nearshore), all year in deep water
- Baltic - ship tracks
- Sakhalin, Cook Inlet – dynamic pack ice
- Gulf of St. Lawrence – salinity gradient, broad mix of ice conditions
- Caspian Sea – thin, mobile and static ice, shallow water

Spill Behavior

As an overall subject area, this was universally agreed to be a high-priority area of research in that our current knowledge is drawn from only two previous experimental spills, and a small number of actual incidents.

- Need additional data points from larger scale releases, in 2 to 6/10^{ths} ice concentrations in the following areas:
  - Spreading
  - Advection
  - Evaporation
  - Emulsification
  - Natural dispersion
  - Oil/mineral particle interaction
  - Dispersion, dissolution, oil/water column
  - Biodegradation
- Need additional data to allow modeling of oil drift and spread relative to ice field
- Need to study behavior of IFO's and diesel as well as crude oils
- Oil migration processes in different ice types, particularly rafted and rough ice (as opposed to smooth landfast ice, studied in 80's)
- Determine fate of water soluble components

Surveillance, Detection, Tracking

The overall objective would be to determine the location and extent of oil within an ice field, and improve on a simple visual capability. The higher priority items below were ones that were felt to be achievable, in that they are based on existing proved technology, but that need validation in a full-scale environment. Lower priority items are those that still require significant research before including in a field program.

- Field tests to build on meso-scale tests of GPR or acoustic for spills under or on top of solid ice (buried under snow)
- Laser fluorosensor for exposed spills between floes, on ice: promising system that needs to be validated
- Sensor/system development, validation: assess capability of FLIR and other sensors
- Modeling ice and ice/oil movement, correlate local/regional wind data to movements
- (Low) Detecting oil within ice (rough ice)
- (Low) Determine slick thickness
- (Low) Remote sensing to detect behavior changes
- (Low) Use of ROV / AUV for underwater detection

In Situ Burning

The first four items on the list were felt to warrant full-scale experimentation based on meso-scale research and likelihood of success. Collecting residue and measuring flame temperatures were felt to be uncomplicated add-ons that should be documented in any event.

- Field tests of chemical herding agents to enhance burning in loose pack ice conditions: 2 to 6/10^{ths}, validate meso-scale tests
- Use of robust fire booms in light ice (i.e., 3/10th and less)
- Validate guidelines for ignitable slick thickness, burn efficiency shown in meso-scale tests
- Collect residue to determine properties with regards to fate (particularly sinking) and toxicity to marine species
- Measure flame temperature using simple IR devices, re: flame/fire properties
- (Low) Monitoring of plume for smoke constituents
- (Low) Research and testing of alternative ignition sources

Dispersants (Natural + OMA + chemical)

Note that this heading includes the use of dispersants or oil-mineral aggregates (OMA), applied to a spill to promote its dispersion and enhance its natural degradation. The items below were considered to be high priority, pending (in some cases) ongoing tank research. Several topics were ranked as lower priority due either to their need for additional small-scale testing or not necessarily requiring field study.

- Verification of meso-scale tank testing, dispersants in medium to high ice concentrations
- Determine operational limits of dispersant effectiveness in ice
- Determine achievable contact time (aka soak time) before mixing: possible application of dispersant in low energy environment, with mixing later if pack ice diverges or energy increases (e.g. near the ice edge)
- Measurements of mixing energy in pack ice
- Field tests of vessel mixing concept: use of azimuth drive icebreakers to add mixing energy to ice field
- (Low) Test dispersants specifically made for viscous oil (development ongoing)
- (Low) Biological effects/toxicity (does not require field study)
- (Low) Verify effectiveness of dispersants and application equipment in cold conditions, air << 0 Celsius (engineering issue, not requiring field study)

Mechanical Recovery

The main idea here was to test skimmers that have recently been developed specifically for oil-in-ice spills, but that have not had extensive testing in the field. It was also suggested that, since there will always be an attempt to skim or mechanically recover oiled ice in certain situations, studies should be done to quantify the overall encounter and recovery rates, including downtime for ice encounters, repositioning, etc.

- Test recently developed oil-in-ice skimmers in larger spills, and in thicker ice
- Need to investigate/test shallow water systems (most oil in ice mechanical recovery concepts require large, deep-draft icebreaking support vessels)

- Field tests of oil-ice separation concepts (building on Japanese meso-scale work) – need more information to assess potential and practicality
- Effects of vessel/ice interactions on encounter / recovery rates: relevant to application of over-the-side skimmers
- Time & motion studies: encounter/recovery rates using existing over-the-side skimmers and/or mechanical recovery systems (i.e., those systems not specifically designed for oil recovery in ice)
- Chemical herders to improve encounter rate
- Determine extreme weather and ice limits for mechanical recovery
- (Low) Pumping and storage issues with cold, viscous oils (can do without being offshore)
- (Low) Measure oil adhesion to ice (can do in lab or basin tests)
- (Low) Use of mechanical herders, e.g. use of water and air streams to herd oil for recovery (needs preliminary research before consideration in offshore field tests)

Development of high-priority ideas

The group was then asked to focus on the concepts that were ranked as "high priority" and to discuss the key parameters that should be considered in the design of the experiments. In each case, suggested key points to consider were:

- Target ice conditions
- Spill parameters (oil type, volume, release conditions)
- Prerequisites to full-scale test
- Logistics requirements
- Possible order with lowest risk, highest chance of success projects first.

Behavior

- A good target would be an approx. 20 m^3 spill volume, in static or diverging pack ice, 2 to 6/10^{ths} concentration
- Should involve several releases
- Should involve two crude oils with different properties (addressing pour point issues)
- Possible one or two main spills focusing on two crudes at each end of the API spectrum, combined with smaller (~1m^3) sub-spills to test other variables
- Should involve other products (particularly IFO and diesel)
- Assume that any crude used would be buoyant to avoid possibility of sinking
- Spill should be followed for 5 to 7 days
- Time needed on site to release and follow spill will be driver for logistics cost and resources
- Integrate with on-going small- and meso-scale work on oil in ice behavior (U.S., Canada, and Norway)

Surveillance

- Confirm performance of systems such as FLIR, laser fluorosensor, GPR, acoustics etc.
- Daylight focus but also need to evaluate night capable systems
- Main emphasis should be on off-the-shelf systems that have promise (e.g., laser fluorosensor, GPR)
- Logistics challenge with regard to positioning a/c, helicopter range, distance from shore, time on site
- Satellite arrangements – consider need to book platforms in advance
- Valuable to have a helipad capable vessel to increase available surveillance time
- Site selection considerations: Airport proximity affecting endurance of surveillance airplane
- Need to detect and map oil under ice as well as oil on surface of floes and between floes
- Trajectories of oil in ice over period of weeks – differential movement rates, oil/ice divergence etc.
- Oil under and within ice: initial focus should be on oil in smooth ice – rubble, ridging much more challenging
- Validate use and performance of ice tracking buoys

In Situ Burning

- Determine if it is possible to burn without new technology in 2 to 6/10^{ths} concentration, with rapid spreading
- Evaluate potential of herders as priority in open pack: validate meso-scale work with herders in lab and tank tests
- Possible fire-boom trials in later spills with small support vessels
- Need a series of spills, with a range of conditions, to evaluate the operating limits
- Good small- and meso-scale data-ready for full-scale
- Helicopter-borne devices will be primary tool for ignition
- Evaluate procedures for residue recovery
- Focus on burning oil between floes (sufficient info for burning on ice surface)

Dispersants (Natural + OMA + chemical)

- Need to measure mixing energy within pack ice (experiments underway at DFO to establish baseline)
- Focus on dispersing oil in leads between floes
- First priority is to repeat recent Ohmsett tests with slush/brush 9/10^{ths} ice; move to lower concentrations with other parameters later
- Target location – MIZ with ocean swell to achieve sufficient mixing energy
- Mass balance in field setting extremely difficult to achieve (impossible?): may have to rely on relative measures of dispersion effectiveness
- Fluorosensor as possible means of qualitative determination of effectiveness in low ice concentration (consider use of ROV/AUV's)
- Vessel or helicopter for application
- Consider having means of adding mechanical energy available on site

- Expand meso-scale envelope of ice and oil parameters before field testing in more open pack
- OMA small-scale knowledge is good: lack full-scale data and data in ice
- Series of small-scale spills in the order of few bbl sufficient to test natural dispersion (plus chemical or OMA)
- Need much higher oil volumes with tests involving vessel mixing (high power props)
- For vessel-mixing experiments, cost and logistics constraints may prevent use actual azimuth-drive icebreaker - consider using scale-model "mixing system"

Mechanical Recovery

- Logistics may be considerable to support large, heavy systems e.g. icebreakers etc.
- Small ice capable work boat minimum resource with capabilities such as:
  - On deck storage tanks
  - Skimmers with extending cranes for over the side deployment etc.
  - Lots of sorbents
- Existing Baltic systems could be difficult and expensive to redeploy to other areas
- Need proof of cold temperature reliability before accepting systems for test
- Floe size is a key factor in utilizing Baltic systems designed for use in sea lanes
- Conduct meso-scale tests of herders to determine if they can enhance skimmer encounter rates
- Target batch spills in close pack ice – over 6/10^{ths} to achieve natural containment
- Encounter rates are key to all evaluations of mechanical systems
- Mechanical recovery could utilize large spills used for fate & behavior experiments (Note: would unavoidably involve weathered, possibly thin slicks)
- Also need dedicated spills to provide fresh oil for immediate recovery
- Look for cross-over with other experimental components to minimize spill volume

For all techniques/concepts: identify crossover opportunities to maximize the research opportunities from the minimum number of spills. For example, surveillance and tracking tests could be done in conjunction with behavior tests, skimming tests might be able to follow almost any other tests, etc.

Program Coordination

The final component of the workshop was an open discussion of several overall project management issues, including:

- Site location and timing - options and tradeoffs
- Potential benefits of international collaboration to reduce overall project risk
- Permitting requirements
- Identify other potential partners not present or invited

Site location

A likely location for the experimental spill would be in the Arctic to qualify for Canadian International Polar Year (IPY) funding (see further discussion below). The specific location in the Arctic would be further dictated by where DFO vessels would otherwise be. In the early stages of experimental planning, Ken Lee will work on linking the project with planned areas of DFO ship operations, with a likelihood that they would be in the Western Arctic. Beaufort Sea is seen as a priority area, with a renewal of offshore exploration in the planning stages. However, there would be significant logistical, timing (short, unpredictable occurrence of ideal ice conditions), and cost challenges.

There would also be a potential opportunity to do a controlled oil spill in the Gulf of St. Lawrence. This would not qualify for IPY funding, but would likely be funded internally within DFO for both OMA and dispersion work.

Need to keep the options open re: site location. On key reason is that there is a risk, in any specific location, of not achieving target ice conditions. For example, in the Beaufort, there is a very narrow opportunity to find the target of 2 to 6/10^{ths} ice concentration. There is a much greater chance of finding such ice conditions on the Canadian East Coast or in the Eastern Arctic. Also important to remember that all of the logistics used to support Beaufort exploration (and spill research) in the 70s and 80's has gone – this would make Arctic work very difficult and costly. A potential spill in the Davis Strait/Baffin Bay marginal ice zone could benefit from the wider range of ice concentrations persisting for longer periods, providing more flexibility in planning and performing the experiment.

The International Polar Year (IPY) program is funding a large number of Arctic experiments around the globe, of which the proposed oil spill would be one component. Canadian government will develop the necessary logistics support infrastructure as part of their IPY effort. Emphasized importance of using a dedicated scientific research vessel, rather than trying to link with non-dedicated vessels, for example, CCG vessels may end up being called away on SAR duties.

International Collaboration

Suggested that we need international collaboration with Norway to share resources and achieve the maximum R&D effectiveness. For example, a series of experiments based in different countries, with opportunities in each one to bring in other research vessels, e.g. USCG + helo support, Russian, Finish icebreakers etc.

In the event that research programs are combined, there would be a mix of goals and objectives between spill locations in Norway and Canada. Questions were raised as to whether funders will simply give to the projects, which most closely met their specific needs? Answer – not with an integrated program that makes the best use of collaboration and resource sharing between countries.

There are already special agreements in place for cooperation with other EU Baltic countries.

A cooperative effort could also bring together countries that in the past have not got together.

SINTEF sees definite value in collaboration, envisioning a series of spills, over time, in various locations in N. America and Europe.

Need to look at the Arctic as an area rather than as a collection of individual countries. Shell wants to see this as a program where the pieces discussed here are brought together maybe through the pre-Joint Industry Project (JIP) in Norway and a subsequent industry-wide JIP. The objective of participants in the existing pre-JIP is to see the alignment of goals and projects between all countries.

Participants should investigate their national participation in IPY, determine points of contact, and determine "national" plans to feed into integrated international program.

Re-iterated that the goal is not just to have a DFO program, but also to have an international program with a Canadian component. This is much more work than any one group can take on. Considered an absolute necessity to share both the workload and funding between countries. There would be no problems with taking a Canadian research ship to Norway: Keep in mind that BIO is a "blue-water" institute with international reach.

IPY and Other Possible Avenues for International Funding
Need to submit proposals to respective countries. International IPY coordinating office then clusters the different submissions. Can come in as a team effort done internationally with different components submitted under the same project number. IPY wants collaboration between university, government, industry, public etc. As this project is not pure science in the traditional mould of NSF proposals, it will have a much stronger chance at the IPY review level by incorporating industry leverage, training for young scientists, tie-in with impact on Arctic communities, etc. Proposal due date: final deadline as little as 1 to 2 months. From IPY web site, www.IPY.org, Jan 16 is date for 3rd call for full proposals – not clear if this means an actual deadline for submitting or simply a call for proposals. Nov 11 to 12, 2005 meeting to discuss Arctic Research connected to IPY in Copenhagen. Work must represent groundbreaking science with engineering support covering the oil recovery, system evaluation aspects etc. Key is to present a heavily leveraged program with industry partners.

IPY projects must have a "science" focus, but will need industry partners for "engineering" aspects of project. Partners will involve straight $$ and in-kind support. IPY proposal will need to identify PI's and Joint PI's from different countries. IPY will judge on basis of scientific credibility, peer review etc. Need to identify scientists within industry with strong science credentials (e.g., publication history, international reputation) to fill this role.

How does the money flow? If proposals are approved, funds are committed to the through the national IPY offices of the respective countries – e.g., Canadian office will fund Canadian participants and work, Norway to its own etc. all under the integrated project umbrella. At the international level, IPY runs from 2007-2009. Canada's IPY program funding will run longer to 2011 - each country may have different end point.

Definite value in cooperative effort. Note Nov 22, 2005 meeting in Sweden with authorities and HELCOM in early Dec 2005 as upcoming opportunities to market project concept. Marketing would benefit from a package of synthesized workshop findings, good slide presentation on experimental rationale, background on oil/ice behavior and countermeasures, IPY connection, etc.

Order of magnitude guess as to possible program cost: In 1993 the Newfoundland Offshore Burn Experiment (NOBE) cost $4 million, 1986 Nova Scotia spill in broken ice in today's dollars would cost ~$1 to 2 Million (3 small spills over a few days only) Estimate for an international multi-year effort with a series of spills could reach ~ $10 million total including support in kind or ~$5 to 6 million in real dollar terms over 3 years. Russian involvement would add cost if spills were in another country's waters.

Norwegian current pre-proposal study concludes in January with workshop. Also in November, concluding ARCOP program with recommendations. SINTEF is interested in a cooperative program but needs further time to study program concept and review prior to committing.

Alternative source of international funding ($100 Million plus) could be 7th Framework Programme, EU 2009 - needs a lot of homework to penetrate with very complicated application process

Ian Buist (SLRoss) offered to volunteer time to handle the ISB part of the program - would need funding for travel depending on meeting schedule/location.

Permitting issues

Need to inform aboriginal groups at an early stage in experimental planning. Ken Lee has already met some of the native leaders and Steve Blasco of DFO has established contacts with native groups. Marty Bergman (head of northern research) DFO Winnipeg would be a key contact for this. There is also a group in Environment Canada that is involved in preparing assessments, environmental reviews. Need to present program information at community meetings, educate public as to benefits. This approach has been successful in past programs involving experimental spills in Canada.

In response to a question, the likelihood of gaining permit approval for an experiment in Canadian Arctic waters was estimated at ~50%.

Any permit issues with a spill in the Gulf of St. Lawrence? Answer: Probably will not get support from Department because it would not qualify for funds from IPY. Note - IPY does not cover up front development work before 2007 or any field activities outside of Arctic.

Potential Funders and Interested Parties

An initial listing of potential funders and partners and organizations contacted for the workshop was expanded through an open discussion into an extensive tabulation of key industry groups, oil spill cooperatives, Universities and institutes, and government agencies that could have an interest in a program of experimental spills (Appendix D). At some point in the future, a contact sheet will be developed to notify these organizations of the experimental planning process and opportunities to become further involved.

Path Forward

The workshop concluded with a review of the earlier stated "goals and expectations" of the participants and an agreement that the workshop succeeded in addressing all of the key issues There was consensus on the need for international cooperation in order to tackle the extensive list of worthy projects, and to successfully execute the research program in the most effective manner maximizing the use of available resources and funding.

A contact list circulated among the group identified 12 participants willing to become part of the steering committee to handle follow-up work (Appendix E). The next step in the process will be a tele-conference call within one month to formalize a preliminary steering group and establish a work plan for moving the project forward. Ken Lee will coordinate the steering committee with the initial goals of: preparing a credible proposal for the work outlined in this workshop, and defining a core scientific program with solid rationale for consideration for funding by IPY.

Appendix A
Workshop Attendees and Contact Information

Workshop Attendees and Contact Information

Organization	Contact	Email
AGIP KCO	Mark Shepherd	M.Shepherd@agipkco.org
Alaska Clean Seas	Lee Majors	Planning@alaskacleanseas.org
Canadian Coast Guard	Ron Mackay	mackayrc@mar.dfo-mpo.gc.ca
ConocoPhilips Canada	Ian Denness	Ian.Denness@conocophillips.com
Dept. of Fisheries and Oceans	Ken Lee	LeeK@dfo-mpo.gc.ca
Devon Canada	Peter Millman	Peter.Millman@devoncanada.com
DF Dickins	Dave Dickins	dfdickins@sbcglobal.net
Eastern Canada Response Corp.	Reid McLeod	RmcLeod@ecrc.ca
Eastern Canada Response Corp.	Pierre Samson	PSamson@simec.ca
Environment Canada	Bruce Hollebone	Bruce.Hollebone@ec.gc.ca
ExxonMobil / ENR	Tim Nedwed	tim.j.nedwed@exxonmobil.com
ExxonMobil / ENR	Alexis Steen	alexis.e.steen@exxonmobil.com
Finnish Environment Inst.	Kari Lampela	Kari.Lampela@ymparisto.fi
IVL Swedish Env. Research Inst.	Jonas Fejes	jonas.fejes@ivl.se
MMS	Joe Mullin	joseph.mullin@mms.gov
MMS Alaska	Dick Prentki	Richard.Prentki@mms.gov
NOAA	Debra Simecek-Beatty	Debra.Simecek-Beatty@noaa.gov
NOAA	John Whitney	John.Whitney@noaa.gov
Oil Spill Response Limited	Richard Tatner	RTatner@osrl.co.uk
Oil Spill Response Limited	Lucy Greenhill	LGreenhill@osrl.co.uk
Shell US	Bela James	bela.james@shell.com
Shell International	Knut Bakke	knut.bakke@shell.com
SINTEF	Ivar Singsaas	Ivar.Singsaas@sintef.no
SL Ross	Ian Buist	Ian@slross.com
SL Ross	Steve Potter	Steve@slross.com
Statoil	Arne Myhrvold	ArneMyhr@Statoil.Com
US Coast Guard	Kurt Hansen	K.A.Hansen@ uscg.mil

Organization	Website
Alaska Clean Seas	www.alaskacleanseas.org
ConocoPhillips Canada	www.conocophillips.ca
Dept. of Fisheries and Oceans	www.dfo-mpo.gc.ca
DF Dickins	www.dfdickins.com
Eastern Canada Response Corp.	www.simec.ca
Finnish Environment Institute	www.environment.fi
IVL Swedish Env. Research Inst.	www.ivl.se
MMS	www.mms.gov
Oil Spill Response Limited (OSRL)	www.oilspillresponse.com
SINTEF	www.sintef.no
SL Ross	www.slross.com
US Coast Guard	www.rdc.uscg.gov

Appendix B
Background Information Document

Workshop to Determine the Scope of an Experimental Oil Spill in Pack Ice in Canada

Background Document

October 20, 2005

submitted to:

United States Department of the Interior
Minerals Management Service
Herndon, VA

by:

Stephen Potter, P.Eng.
S.L. Ross Environmental Research Ltd.
Ottawa, ON Canada
Email: Steve@slross.com

and
David Dickins, P.Eng.
DF Dickins Associates
La Jolla, CA
Email: info@dfdickins.com

and
Kenneth Lee, Ph.D.
Centre for Offshore Oil and Gas Environmental Research
Fisheries and Oceans Canada
Bedford Institute of Oceanography
Dartmouth, NS

Table of Contents

1. Background

The U.S. Minerals Management Service and the Canadian Department of Fisheries and Oceans will conduct a planning workshop on November 1-2, 2005 in Dartmouth, Nova Scotia. The workshop will bring together all parties and stakeholders interested in an experimental oil spill in pack ice.

Small and meso-scale tank scale tests have been highly effective for screening hardware (e.g. new skimmers) and investigating new technologies for pack ice (e.g. burning in slush; herders in broken ice; dispersants in broken ice). However there are serious limitations in scaling to an open ocean pack environment. At some stage, in order to build confidence and confirm that strategies will actually work in the "real world" there is no substitute for a full-scale field spill. Field trials are essential to not only validate technologies and improve our basic scientific understanding but as a rare opportunity to train and educate responders and stakeholders in a realistic setting.

The following is an introduction to the subject. It is intended to provide a focus for workshop discussions, and ensure a common starting point in terms of "what has been done" and "what needs to be done" in the five main subject areas of spill behavior, detection and tracking, mechanical recovery, in situ burning, and dispersant use. Specifically, the background document covers:

- The state-of-the-art and major knowledge gaps in oil spill behavior and potential response tactics in a pack ice environment;
- The history of experimental spills in pack ice focusing on the two previous large-scale field projects (1986 and 93); and
- Possible improvements in knowledge or technology that could be realized by re-examining response tactics in a full-scale ice environment.

This draft background document has three attachments that contain:

- Confirmed attendees with names and affiliation (Attachment A)
- Draft agenda proposed for the November 2005 workshop (Attachment B)
- Summary of project team members and experience (Attachment C)

2. Major Knowledge Gaps in Spill Behavior and Potential Countermeasures in a Pack Ice Environment

The following summarizes the current knowledge base and perceived gaps for spill behavior and the key response areas for a pack ice environment.

Spill Behavior

- Basic understanding of evaporation and spreading processes, extent of natural dispersion, and limitations on oil movement relative to ice for various ice concentrations and ice composition. (Note: current models based on only two field experiments, and would benefit greatly from more full-scale data.)

- Knowledge gaps:
  - Emulsification of oil amongst ice.
  - Quantification of oil "pumped" onto ice edges or into floe interiors by wave action as a function of time and wave energy.
  - Submergence / dispersion of heavy crudes, emulsions, and fuel oils in brash and slush.
  - Modeling of ice drift, to estimate oil/ice advection.
  - Long-term (i.e., months, rather than hours and days) weathering of oil in ice.

Surveillance

- Proved technology (e.g. laser fluorosensor) is available to detect oil floating amongst ice or exposed on top of floes. Not an effective technique for oil under ice, or oil adsorbed or covered by snow on the ice surface.

- Technologies for detecting oil under ice (ground-penetrating radar and other systems such as acoustics and ethane sensing) currently in the development stage, shows promise for locating oil in defined areas such as along a pipeline right of way (i.e., not likely suitable for sweeping large ocean areas to "hunt" for oil).

- Note: Surveillance likely to be part of any experiment for operational reasons and for documentation of spill conditions.

- Knowledge gap: Confirmation of capabilities of laser fluorosensor and other new detection systems requires testing in an operational setting.

Mechanical Recovery

- Recovery in conjunction with containment booms limited to trace ice conditions, contrary to previous assumption that limited operations could be carried out in $3/10^{ths}$ ice or more.

- Recovery using skimmers independent of boom (over-the-side deployment of rope mop type skimmers, or purpose-built oil-in-ice skimmers) effective for certain situations. Low encounter rate will limit their use to relatively thick slicks in close pack ice (i.e., where oil spreading is limited).

- Knowledge gap: Technology developed through laboratory and limited field-testing would benefit from further field-testing under realistic conditions.

- Knowledge gap: recent developments such as herders in ice (investigated with dispersant use in mind), may also have potential for enhancing mechanical recovery effectiveness, and should be tested under field conditions.

In Situ Burning

- Proved technique for certain ice and oil conditions.
- Likely to be very effective in pack ice 6/10ths and greater, if thick enough initially. Ice will restrict spreading of oil, maintaining ignitable thickness for some period after the spill.
- Likely to be very effective in relatively static brash and slush ice based on recent tank tests: field trials would provide further validation.
- Possible to thicken oil in 1/10ths or less using combination of conventional containment boom and fire-resistant boom.
- No proved technique for dealing with oil amongst ice between 3 and 6/10ths. Research currently underway to use surfactants to herd oil spilled amongst ice in this range.
- Knowledge gaps:
  - Field trials to validate tank test findings on burning in brash and slush ice.
  - Subject to results of ongoing tests, field trials to validate test tank findings on use of surfactants to herd oil for burning.
  - Test new generation of fire-resistant booms in light ice conditions.

Dispersant Use

- Until recently, assumed to not be an option due to low water temperatures and reduced wave energy amongst ice. The presence of broken ice does indeed dampen wave energy in a broad sense, but at the "micro" level, energy may in fact be amplified by the reflection of waves amongst ice floes and brash. Some promise based on recent tank tests.
- Tests at Ohmsett (the National Oil Spill Response Test Facility) have proved the effectiveness of dispersants in near-freezing water temperatures, but this is highly dependent on the properties of the oil.
- Subject to oil properties (including viscosity and pour point at near-freezing temperatures), which will worsen as the oil weathers. Time window-of-opportunity may be shorter in freezing conditions.
- Tests at Ohmsett have also proved the effectiveness of dispersants in up to 8/10ths ice with low-amplitude wave conditions.
- Knowledge gap: Field trials to validate recent tank test findings on dispersant effectiveness in cold water and pack ice.

Other techniques
There is emerging interest on the potential use of Oil Mineral Aggregate (OMA) formation as the basis for an oil spill countermeasure technique. Studies have been actively pursued by the international oil spill response community in the laboratory and in small to meso-scale tank tests. Findings from these studies suggest that field trials are warranted:

- Lab-scale research is currently underway to investigate use of oil-mineral aggregates (OMA) for spills of heavy fuel oil in pack ice.

- Research currently underway on use of icebreaker prop-wash to assist in dispersion of slicks treated with dispersants and OMA's.

- The need for feasibility studies in the field has been identified.

3. Past Experimental Spills

This brief summary of experience focuses on the only known large-scale experimental spills carried out in pack ice: Canadian East Coast in 1986, and off the coast of Norway in 1993. Mention is also made of a limited number of selected accidental spills that received systematic documentation in the published literature.

3.1 Canadian Oil Spill in Pack Ice (1986)

SL Ross and DF Dickins (1987) describe the results of three spills of six barrels each of Alberta Sweet Mixed Blend crude oil (s.g. 0.856) into a variety of pack ice forms ranging from a dynamic mix of floes and slush within an open ocean swell, to a more static case of almost complete ice cover with slush-filled leads.

The primary objectives of the study were to evaluate spreading in variable pack ice conditions, document the fate of oil in pack ice (evaporation, emulsification, dispersion), and employ possible countermeasures (in practice limited to in-situ burning).

Ice conditions ranged from 4 to 6/10^{ths} small floes and pancakes in a dynamic 3 to 4 m swell for the first spill to 7 to 8/10^{ths} very close pack and slush/brash- filled leads with very limited swell interaction for the second spill. Floe sizes ranged from an average of 7 to 13 m.

The oil in the first open-pack-ice spill interacted with the ice in three ways: it saturated the brash and slush ice surrounding the floes and pancakes, it splashed into small pancakes of ice, and a very small proportion (few percent at most) of the oil was swept as droplets beneath the floes by the relative motion of the ice and water. The oil in the first spill mixed with the slush ice, which in turn coated the outer rims of small floes and pancakes with an oil stain. In the other two spills, once the oil spread in the lead to saturate the slush ice above the water surface, it essentially ceased spreading or spread very slowly. In ice concentrations over 4/10^{ths} the oil did not drift relative to the surrounding ice.

Although the test crude oil was known to emulsify at cold temperatures, no emulsification was observed amongst the ice. In spite of the potential for much greater turbulent mixing energies than would be expected in many Arctic areas (e.g. Beaufort Sea), the majority of the oil remained at or close the surface. Some large oil droplets were temporarily driven down in the water column but these quickly resurfaced. There was no evidence that any significant portion of the spill was driven down or suspended at depth in the slush.

No attempt was made to clean up the first spill. In the second and third spills, in higher ice concentrations, in-situ burning was effective. Burns lasted about 20 minutes and consumed an estimated 80% of the oil. Residue was recovered with shovels and bagged for disposal. No other countermeasures techniques were tried. It may have been possible to recover the second and third spills by skimming or direct pumping, and in light of recent research, dispersants and chemical herding may also have been applicable.

KEY OBSERVATIONS:
- Oiled mixed with the slush ice and stopped spreading.
- The majority of the oil remained at or near the surface in broken ice.
- Oil and ice tended to move together in over 4/10^{ths} ice.
- No emulsification was observed in spite of the dynamic ice conditions in Spill #1 and the known emulsification tendency of the crude oil used.
- Based largely on data from this experimental spill, simple spreading relationships were developed as a modification to spreading equations for open-water spills.

3.2 Norwegian Oil Spill in Pack Ice (1993)

A series of papers and reports describe the 1993 Norwegian experimental spill in pack ice (Vefsnmo and Johannessen, 1994; Singaas et al. 1994; Johannessen and Jensen - Sintef internal).

The main objectives of the experiment were:
- To study the behavior of oil in broken ice with the emphasis on changing oil properties, oil-ice interactions, drift, and spreading.
- To determine scaling effects for future lab experiments
- To evaluate a variety of response techniques including side effects of the methods used on oil ice and water (in the event, only mechanical clean-up was used))
- To increase overall knowledge of ice field dynamics and to understand the benefits and drawbacks of the ice in aiding or restricting recovery
- To provide data to use as the basis for developing numerical models for predicting oil properties vs. time, and drift and spreading of spills in pack ice.

The spill took place in late April 1993 off the north coast of Norway between the mainland and Spitzbergen. Some 26 cubic meters (163 bbl) was released 45 km inside the ice edge with a surrounding ice concentration of 9/10^{ths}. The oil was Oseberg crude, s.g. 0.853 and pour point -24°C. During a six-day period of sampling and analysis of oil properties and spreading, the slick drifted to within six km of the ice edge, while the ice concentration ranged from 7 to 9/10^{ths}. Wave energy and swell within the marginal ice zone were relatively low throughout the experiment (in contrast to the Canadian 1986 experimental spill #1).

Findings from this spill support the importance of examining pack ice composition on a small scale similar to scale of the oil patches themselves. In this example, 157 barrels of crude oil spread from a starting thickness of 10 cm to 1 cm in 45 minutes after being spilled in 8- to 9/10^{ths} ice. The oil thickness remained constant at just less than 1 cm for four days and then rapidly thinned by another factor of 10 within 24 hours as the ice opened up slightly from 8- to 7/10^{ths}.

As was observed in the Canadian experiment, an insignificant amount of oil was transported to the underside of floes. Vertical penetration of oil into the ice undersurface was limited to about 2 to 3 cm. Oil volumes adhering to the perimeter of ice floes were estimated as 525 cm^3 per meter, amounting to between 2 and 5% of the total oil volume.

A Foxtail rope mop skimmer was the only piece of mechanical recovery equipment used on an operational basis. The support vessel lacked side thrusters and had limited maneuverability in the ice, which hampered the clean-up operation significantly. As the vessel maneuvered to position the skimmer, the ice field was opened locally, causing the oil to rapidly spread and thin, which in turn reduced the availability of oil to the mop (similar vessel influences on natural ice containment were observed in 1986 in Canada) As a result, large quantities of water and slush were picked up together with the oil.

In the end, very little oil was actually recovered, and the spill was allowed to reach open water and degrade naturally in the open ocean. It was judged that in situ burning of the slick (if pursued) would have been successful. With the high ice concentration and low energy levels, chemical dispersants were not viewed as practical options. (Note: Since 1993, opinions on the possible effectiveness of dispersants in broken ice have changed together with the prospects for burning oil successfully in slush and brash - both tending to be more positive).

3.3 Examples of Past Accidental Spills in Broken Ice

A limited number of accidental spills provide detailed observations of oil behavior in developing and broken ice. Selected examples summarized here include:

***Kurdistan*, March 1979:** The *Kurdistan* tanker spill, Cabot Strait, Nova Scotia, 1979 was documented in considerable detail (Reimer, 1980; Trites et al., 1986; Vandermeulen and Buckley, 1985; O'Neil and Thomson - Undated). An estimated 7,000 tonnes of Bunker C was spilled into pack ice intermixed with large areas of brash. The high pour point oil congealed rapidly in the cold water, leading to blobs and oil pancakes with a specific gravity (0.973) greater than the ice and only slightly less than seawater. Small droplets and oil splatters were observed within a few meters of the edges of floes, but most of the oil was thought to be distributed over a broad area mixed at depth within the brash ice. One area sampled was estimated to contain approximately 400 tonnes with oil concentrations of 200 ppm measured within the brash to a depth of one meter. The spill degraded over time into progressively smaller oil particles attributed to the process of mechanical grinding between floes. Oil concentrations in the water column under the contaminated ice were less than 1 ppm.

A subsequent spill of heavy fuel oil in the Gulf of St. Lawrence in newly forming grease ice (Wilson and Mackay 1987) led to a similar condition with much of the oil thought to be incorporated within the new ice. Although the grease ice effectively damped the wind waves, there was still sufficient turbulent energy in the ice pack to force oil particles (particularly heavy oils) into the ice where they tend to remain suspended at depth.

***Bouchard #65*, Buzzards Bay, Massachusetts January 1977:** This accident was documented in detail and led to numerous papers and reports (e.g., Deslauriers and Martin 1978; Ruby et al., 1977; Deslauriers, 1979). An estimated 81,500 gal. of Number 2 (light) fuel oil from a barge spill was transported for large distances, and dispersed under the ice as leads opened, and incorporated into deformed ice as the leads closed. The findings provide a valuable contrast to observed behaviors of heavy fuel oil and bunker C such as in the *Kurdistan* and *Matane* spills.

The following observations focus on the Buzzards Bay spill, combining discussion from various authors (see above). The ice cover at the time of the spill was half landfast and half broken ice. The broken ice consisted of 75 percent ice floes (avg. thickness 30 cm), along with 25 percent hummocks, pressure ridges and rafted ice. Strong tidal currents initially transported much of the oil under the ice, where it rose into openings in the ice and became incorporated into rough ice. An estimated 30 percent of the oil formed pools in the rafted ice, with some oil trapped beneath, and other oil lying in surface pools at the point where one layer of ice rode beneath the other. Many of these pools had depths of 10 cm and contained several hundred gallons of oil (some pools held up to 2,000 gallons). High winds (30 knots) led to spreading of oil on areas of nearby smooth ice from the thick pools in rafted ice. Samples of oiled slush ice at the edges of pools in rafted ice showed 30 percent oil by volume.

Oil incorporated into ridged and hummocked (rubble) was effectively contained but not as concentrated as the pooled oil in rafted ice. Cores through a pressure ridge containing oil showed only oily ice with no direct flow of oil into the core hole.

A heavy snowfall one week after the spill resulted in the formation of an oil/snow mulch containing about 30 percent oil by volume. Oil weathering ranged from 6 to 47 percent oil volume loss depending on the amount of air exposure. Of the 81,150 gallons spilled, an estimated 45 percent was held by the ice in pools, which could be pumped. The remaining 55 percent of the oil contaminated the ice over an area of 23 acres with an average concentration of 0.08 gallons per square foot.

The dispersion of the oil in the Buzzards Bay spill was largely driven by the oil and water density differences and the ice deformation. Winds were a significant factor in transporting pooled oil over the ice surface. When leads opened in the very close pack ice, the oil was released from under the ice. This oil then became incorporated into the deformed ice when the leads closed again. In some cases, oil was pumped onto the ice surface by this type of action.

Although the shorefast ice acted as effective barrier preventing any oil contamination of the beaches, oil was concentrated in the brash ice separating the bottom fast (immobile ice immediately along shore) and the floating ice moving up and down with the tides. The proportion of oil adhering to the ice, was directly related to the porosity of the ice at the time of the spill [decaying ice in spring and newly forming ice at freeze-up are both extremely porous].

***Antonio Gramsci,* tanker spill, Gulf of Finland, February 1987** (Hirvi, 1990; Hirvi et al. - several internal Finnish government reports covering oil behavior and drift modeling).

Estimated spill size was 570 tonnes of Soviet Export Blend crude (0.849 s.g.) with a low pour point (-15°C). Approximately 80 tons were recovered. Surrounding ice cover consisted of a small patch of new ice around the ship where it grounded and remainder with close pack and ridging. Oil divided into a number of separate patches with limited movement in March. In April, the pack ice became more mobile and the oil eventually spread to cover 2500 km^2 by the end of break-up in May. Total evaporation was estimated at 30% with 20% loss while in heavy pack in February. The Finnish government conducted a series of model simulations correlated with observations of the oil slick separation and divergence over time. This spill represents possibly the only example where a spill in broken ice was tracked and monitored for several months through the stages of ice decay and break-up. Lampela (2000) summarizes this and other spills in ice in the Baltic region.

3.4 Summary

Some key observations from the field experiments and accidental spills in pack ice include:

- Light fuel oil or medium crude oil released from the ice undersurface tends to rise and remain on the surface of water and slush in leads, or in newly forming grease ice.
- Heavy fuel oil or bunker oil particles tend to be driven down into slush and brash between the floes and can remain suspended at depth (one meter or more).
- Depending on pour point, gelling may be a key mechanism affecting the oil distribution and spreading in pack ice.
- Oil continues to evaporate while entrained in pack ice, even after being mixed with or covered by snow.
- Wind herding creates thicker oil layers at the downwind edge of open leads.
- Slush or brash in leads effectively prevents spreading.
- Small oil droplets can be swept under floes in a dynamic pack ice environment but the volume transported in this fashion amounts to an insignificant % of the total spill (except in case of heavy fuel oil, crude or bunker spills)
- On regional scale, oil and ice tend to move together in high ice concentrations (over $6/10^{ths}$)
- Localized spreading and film thickness are very sensitive to relatively small changes in ice packing in the range 7 to $9/10^{ths}$
- Lead pumping once thought to result in large portions of the spill being transported into the interior of floe surfaces happens to a small degree but not to the extent observed in tank tests.
- Emulsification and natural dispersion appear to be minimal in the presence of any substantial ice cover but these processes are still not well enough understood (tank tests have produced contradictory results)
- Ice acts as natural containment to restrict further spreading from the point where the oil contacts the ice surface. However, the simple presence of ice by itself does not necessarily result in thick oil films or act to thicken the oil once it has spilled. This is an important consideration in evaluating strategies such as in-situ burning associated with for example continuous oil releases to the surface of a rapidly moving ice cover.

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Appendix: Project Team

SL Ross Environmental Research, DF Dickins Associates and COOGER will jointly complete the preparations for the workshop and facilitate its conduct.

SL Ross Environmental Research Ltd. (www.slross.com) is a consulting firm specializing in oil spills and their control. The company has four full time professionals who have a combined experience in oil spill matters of 100 years. The company has performed more than 350 major studies for government and industry clients.

DF Dickins Associates Ltd. (www.dfdickins.com) is a consulting company with a twenty-seven year record of environmental project management, and engineering research for resource development companies in the United States, Canada, Europe and Russia. The company specializes in studies associated with offshore oil exploration and development, and the marine transportation of oil in ice covered areas around the world.

The Centre for Offshore Oil and Gas Environmental Research (www.dfo-mpo.gc.ca/science/cooger-crepge/) was established by Fisheries and Oceans Canada to coordinate the department's nation-wide research into the environmental and oceanographic impacts of offshore petroleum exploration, production and transportation. The Secretariat office of this national research center, based at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, seeks to improve scientific knowledge, identify priority research needs, and coordinate and implement collaborative research efforts.

Key Project Personnel

Steve Potter, B.A.Sc., P.Eng., will manage the organization of the workshop. Mr. Potter has considerable experience in the capabilities and limitations of countermeasures in various ice environments, and has been participated in several field experiments and spill responses in Arctic environments.

Ian Buist, M.A.Sc., P.Eng., will assist Mr. Potter with the workshop preparations. Mr. Buist is a leading expert on Arctic oil spill behavior and countermeasures and an acknowledged authority on *in situ* burning. He has been closely involved in oil spill fate and countermeasures research for 25 years. He conducted several of the major Canadian experimental spills of oil in ice in the 1970s and 1980s.

David Dickins, B.A.Sc., P.Eng., has over 30 years of experience with marine environmental projects, focusing on research into oil spills in ice. His background includes participating in or managing seven large-scale experimental oil spills in the Arctic and Atlantic Ocean, and chairing and facilitating four international conferences on the topics of Arctic marine transportation, in situ burning, and oil spills in ice.

Kenneth Lee, Ph.D., is a Senior Research Scientist and Executive Director of the Centre for Offshore Oil and Gas Environmental Research, Fisheries and Oceans Canada. Dr. Lee will manage the overall experimental spill effort.

Appendix C
Workshop Agenda

Workshop to Determine the Scope of an Experimental Oil Spill in Pack Ice
November 1 and 2, 2005
Bedford Institute of Oceanography, Dartmouth, Nova Scotia Canada

Agenda

Tuesday November 1

0900	Welcome	Ken Lee
	Introductions	Steve Potter
0915	Background: Workshop objectives and rationale	Dave Dickins
	Potential for international experimental spill in ice	Ken Lee
0945	Comments on background paper, Survey of participants expectations	Steve Potter
1000	Past experimental spills and workshops	Dave Dickins
1015	Break	
1030	State-of-the-art in broken ice spill response: recent and ongoing research	
	Update on recent development work Tests of oil-in-ice skimmer	Kari Lampela, Finnish Environment Institute
	Alaskan regulatory experience Containment & recovery experiments in ice	Lee Majors Alaska Clean Seas
	Update on recent research and priorities for the future	Ivar Singsaas SINTEF
	Summary of various oil-in-ice projects	Joe Mullin, Minerals Management Service
1200	Lunch break	
1315	OMA research	Ken Lee, Dept of Fisheries and Oceans
	Recent spills-in-ice research, incl. dispersant application	Tim Nedwed ExxonMobil
	In situ burning in pack ice	Ian Buist, SL Ross Environmental Research
1500	Break	
1520	List potential research topics, focusing on concepts: • that have shown promise at small- or mid-scale • that could benefit from re-examination or testing in a full-scale ice environment	
1630	Adjourn	

Wednesday November 2

0900 Review of specific research topics — Steve Potter
- Chances of success
- Potential benefits

0945 Development of high-priority ideas — Dave Dickins
- Target ice conditions
- Spill parameters (oil type, volume, release conditions)
- Prerequisites to full-scale test
- Logistics requirements

1030 Break

1050 Completion of Development of high-priority ideas

1130 Break to visit new wave tank facility at BIO — Ken Lee

1230 Lunch

1330 Program Coordination — Ken Lee
- Site location and timing - options and tradeoffs
- Potential benefits of international collaboration to reduce overall project risk
- Identify other potential partners not present or invited
- Permitting requirements

1500 Break

1515 Wrap-up — Dave Dickins
- Summary of workshop conclusions and path forward
- Identify those willing to form management committee for followup work
- Establish mechanism for next contact, teleconference etc.
- Summarize next steps

1600 Adjourn

Appendix D
Potential Funders and Interested Parties

Potential Funders and Interested Parties

Key Industry Groups
Agip KCO (N. Caspian - Kashagan)
BP (Alaska, Canada, Russia, Sakhalin 3/4/5)
ChevronTexaco
ConocoPhilips (Alaska, Norway, Canada, Russia)
ExxonMobil (Sakhalin 1)
Lukoil
Marathon
New Arctic Operators (Pioneer, Devon, EnCana)
Petroleum Association of Japan (PAJ)
Sakhalin Energy Investment Company Ltd. (SEIC, Sakhalin 2)
Shell International (Alaskan Beaufort, Russia etc.)
Statoil ASA (broad Arctic interests)
Total

Oil Spill Cooperatives
Alaska Clean Seas
Cook Inlet Spill Response Inc. (CISPRI)
Eastern Canada Response Corporation (ECRC)
Mackenzie Delta Cooperative
Norwegian Clean Seas Association for Operating Companies (NOFO)
Oil Spill Response Limited (OSRL)

Universities and Institutes
Arctic Council (Emergency Prevention, Preparedness, and Response, EPPR)
Arctic Council (Protection of the Arctic Marine Environment (PAME)
Canadian Hydraulics Centre NRC
Central Marine Research and Design Institute (CNIIMF)
IVL Swedish Env. Research Institute
Memorial University (C-CORE)
Murmansk Marine Biological Institute
National Science Foundation (NSF)
Oil Spill Recovery Institute (OSRI)
Prince William Sound Oil Spill Recovery Institute
Sakhalin Oil and Gas Institute
University Centre in Svalbard (UNIS)
University of New Hampshire
U.S. Arctic Research Commission
VTT Technical Research Centre of Finland

Government Agencies
Alaska Department of Environmental Conservation (ADEC)
Department of Energy (U.S.)
Environment Canada
Environmental Protection Agency (U.S. EPA)
Environmental Studies Research Funds (ESRF, Canada)
Finnish Environment Institute
Fisheries and Oceans Canada (COOGER)
Japan Maritime Safety Agency
Minerals Management Service (MMS)
National Science Foundation (NSF)
National Oceanic & Atmospheric Administration (NOAA)
ONR (U.S.) (Office of Naval Research?)
Program of Energy Research and Development (PERD, Canada)
Swedish Coast Guard
Swedish Rescue Service Agency
U.S. Coast Guard R&D Center

Appendix E
Initial Steering Committee

Initial Steering Committee

Organization	Contact	Email
AGIP KCO	Mark Shepherd	M.Shepherd@agipkco.org
Alaska Clean Seas	Lee Majors	Planning@alaskacleanseas.org
Canadian Coast Guard	Ron Mackay	mackayrc@mar.dfo-mpo.gc.ca
Dept. of Fisheries and Oceans	Ken Lee	LeeK@dfo-mpo.gc.ca
DF Dickins	Dave Dickins	dfdickins@sbcglobal.net
Environment Canada	Bruce Hollebone	Bruce.Hollebone@ec.gc.ca
ExxonMobil / ENR	Tim Nedwed	tim.j.nedwed@exxonmobil.com
ExxonMobil / ENR	Alexis Steen	alexis.e.steen@exxonmobil.com
MMS	Joe Mullin	joseph.mullin@mms.gov
NOAA	To be identified	
Shell US	To be identified	
SL Ross	Ian Buist	Ian@slross.com
SL Ross	Steve Potter	Steve@slross.com
Statoil	Arne Myhrvold	ArneMyhr@Statoil.Com