Hamburg Ship Model Basin (HSVA)
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GROWTH Project GRD2-2000-30112 "ARCOP"

DEVELOPMENT OF NEW OIL SPILL RESPONSE CONCEPTS

WP 4:	Environmental Protection and Management System for the Arctic
WP 4.2.1.2:	“DEVELOPMENT OF NEW OIL SPILL RESPONSE CONCEPTS ”

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Short Description

The aim of this project has been to identify research needs for improvement and further development of oil spills response concepts for use in the ice-infested waters. The project is part of the ARCOP (Arctic Operational Platform) program, a research and technology development program with the overall objective to form an operational platform for development of petroleum transportation in the Arctic region. The focus of the ARCOP program is the shipping route from the loading terminal at Varandey to Murmansk.

Three main subjects have been discussed in this report: mechanical recovery, in-situ burning and use of dispersants. The potential for improvement/further development and "winterization" of existing equipment, is probably higher than development of new concepts. For mechanical recovery it is suggested to build on existing equipment, including also some recent developments, to further develop it to be more operateable in the harsh environment encountered in the Arctic and to handle the mixture of oil and ice in a best possible way. For in- situ burning it is important to define better the operational "window of opportunity" for ignition and efficient burning for various oils and to include that in oil weathering models. The ignition technology should be further developed for use in remote areas and the potential for use of in- situ burning on remote shorelines and inaccessible mudflats should be evaluated. The documentation for operational applicability of dispersants should be improved in Arctic areas. Application technology and creation of artificial turbulence to start the dispersion process are other key elements. The potential ecological effects from dispersed oil are of public concern and should be studied with focus on Arctic areas.

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Executive Summary

The aim of this project has been to identify research needs for improvement and further development of oil spill response concepts for the use in ice-infested waters. The project is part of the ARCOP (Arctic Operational Platform) program, a research and technology development program with the overall objective to form an operational platform for development of petroleum transportation in Arctic regions.

The core issue in ARCOP is the transportation of oil from a terminal at Varanday (northwest of Russia) to the European market. This could be done either by tankers going all the way from Varanday to western Europe, or to some reloading terminal, for instance in the Murmansk area. We are talking about year round shipping, which means that the transport will go through areas with ice during the winter months. Sea transportation of oil and gas products from the Pechora and Kara Sea region as well as oil/gas exploration in arctic waters will increase the risk of oil spills in this highly vulnerable environment. Most of the research needs highlighted in this report are valid both for the part of the transportation route from Varanday to Murmansk covered with ice in some months of the year as well as other ice covered Arctic areas.

To establish an efficient oil spill contingency for winter conditions in the Arctic areas requires both, improvements of existing methods and developments of new oil spill response concepts. Up to the present, there has been a lack of field trials for operational testing of combating techniques referred to the Arctic. Three main subjects have been discussed in this report: mechanical recovery, *in-situ* burning and use of dispersants. Remediation technologies and shoreline cleanup are also important aspects when discussing countermeasures in Arctic areas, but these technologies are beyond the scope of this report.

The following recommendations are given for the various topics of research and development:

Mechanical recovery:
Due to the low temperatures normally found in Arctic regions and the presence of ice, existing response equipment needs to be modified to operate under harsh conditions (winterization). This may include improved ice processing, reduction of icing/freezing (heat supply), transfer of recovered products (including ice) and separation of oil from ice.

The MORICE[1] recovery system is one of the most recent developments for mechanical recovery of oil in ice and has a potential for further improvement and commercialising. The same is also valid for the Finnish Vibrating Unit, which is also a recent development.

The Norwegian engineering company FRAMO Engineering AS has described some technical solutions for oil spill scenarios around oil installations and vessels, by use of existing booms, powerful vessels and their weir skimmers with high pumping capacity. They also describe a concept for recovery of oil under the ice. These ideas should be further evaluated and there may be a need for winterization of the equipment.

***In-situ* burning**
In-situ burning may have a considerable potential for use in ice conditions and may often be the only practical option for removal of surface oil in such situations. Much research, including field activities, has been done in this area, both in USA/Canada and in Norway. In this report the importance of identifying the “window of opportunity” for ignition and efficient burning of oil spills in the Arctic has been stressed. The “window of opportunity” will vary between different crude oils and oil products. Based on a systematic laboratory testing and field validation it is

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[1] MORICE : **M**echanical **O**il Recovery in **Ice**-infested Waters

suggested to include the "window of opportunity" for burning as a standard prediction from weathering predicting models.

Ignition technology is another important aspect that needs to be looked into. When operating in remote areas it is necessary to have igniters that do not necessarily rely upon aerial ignition.

Even if *in -situ* burning has the largest potential in ice it should also be evaluated as a potential response option for remote shorelines and inaccessible mudflats in Arctic areas.

Use of dispersants

There is also a potential for use of dispersants in cold-water environments with ice. For obtaining an effective dispersant operation in Arctic areas, it is important to evaluate the following critical parameters:

- Access (contact) of the dispersant to the oil.
- Sufficient mixing energy for the dispersion process.
- Oil properties at low temperature (weathering degree), with special focus on viscosity and pour point.
- Dispersant performance and properties under the relevant conditions (salinity, temperature, oil type).

Recent promising results in industry-sponsored tank tests have spurred a re-examination of dispersants as a potential strategy for certain oil-in-ice scenarios (Mullin, 2004). The use of icebreakers or other vessels, in particular with azimuth propulsion systems, to introduce the necessary mixing energy, in combination with dispersants formulated for longer retention by viscous oils, could lead to dispersants becoming a practical response option for oil spills in ice. A combination of systematic laboratory and tank studies and validation in field experiments is needed to make dispersants useful as a practical countermeasure in ice covered waters.

It is important to improve the documentation of the effectiveness of dispersants at low temperatures (both water and air), at low salinity and the presence of ice. This may include a screening of existing products, potential development of new products and to find the optimal dosage for various oil types.

Application technology is another key element. Both aerial application, vessel application and the potential injection of dispersants from the seabed should be further explored. Due to the wave damping effect by the presence of ice means and techniques of creating "artificial turbulence" should be further investigated.

The potential ecological effects caused by the dispersed oil droplets and the water-soluble oil components often cause public concern. The potential effects should be studied both, for ice-covered waters as well as at the ice edge. The fate and degradation of the dispersed oil should also be further studied.

1 Introduction

Shipment of oil from Russia to Western Europe and USA is increasing rapidly, and will continue to increase in the years to come. ARCOP (Arctic Operational Platform) is a research and a technology development project with the overall objective to form an operational platform for the development of oil and gas transportation in the Arctic region.

The ARCOP shipping scenario is characterized by the following parameters (Evers *et al.*, 2004):

- Cargo: Crude oil from Varanday to Murmansk (year around)
- Tanker alternatives: 120 000 dwt, 90 000 dwt and 60 000 dwt tankers
- Size of the biggest crude oil tank is about 10 000 dwt (in 120 000 dwt tanker)
- Due to design of tankers, the defined ARCOP ice conditions for the shipping scenario are very detailed. Here we only refer some of the parameters:

○ Ice thickness (average winter max)	1.1 m
○ Rafted ice with a maximum ice thickness	2.4 m
○ Average ice pressure intensity (0-3)	1
○ Average ice drift speed	0.2 m/s
○ Ice drift direction	irregular (wind driven)
○ Maximum ice concentration	100 %
○ Time of year	March
○ Minimum air temperature in March	- 44° C
○ Typical air temperature in March	-14.4°C

Based on hydro meteorological station data, average air temperature in the Varandey area in March is -14.4 deg. C (recorded minimum is –44°C, maximum is +3°C). Near Murmansk it is higher by about 4°C. However, this is applicable to coastal line. Air temperature in this part of the sea is 2°C to 5°C higher (depending on location: due to Gulf Stream influence; gradient of air temperature is very significant). Figure 1.1 gives an example of ice coverage and wind fields in the transportation area in March (Johansen, 2005).

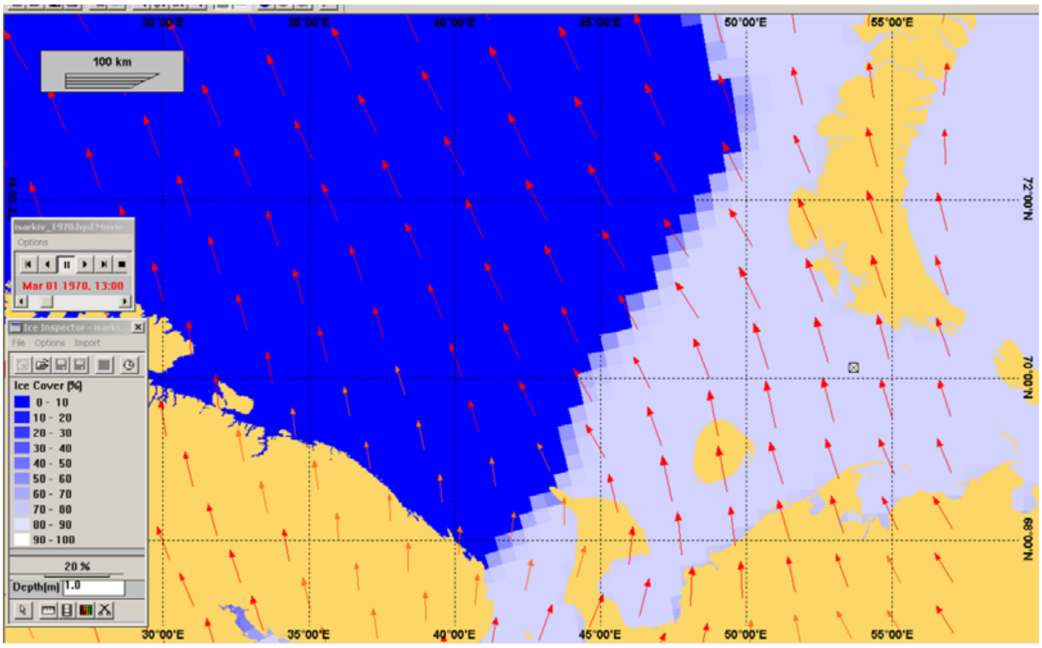

Figure 1.1 Example of ice coverage and wind fields in the transportation area as per March 1. Data at 24 hour intervals in 20 × 20 km resolution. Data provided by MI.

The objective of this sub task in the ARCOP project, work package 4 “Environmental Protection and management System for the Arctic”, is to provide research needs for further technical work according to improvement and development of new oil spill response concepts in Arctic and ice-infested waters as a basis for development of an environmental protection and management system for the Arctic region. The main focuses in this report are divided into following sections:

- Improvement and development of mechanical recovery
- *In-situ* burning
- Use of dispersants

The goal is to give common recommendations of research needs for the improvement of existing equipments, and developing new technologies in the assessment to the environmental safety. A future approach should be to develop Operational Model Tools both for contingency planning and decision making during response operations, for oil spills in ice-infested water. The model concepts could be important tools to predict the “time window” to determine the most efficient response techniques to combat various types of oil spill in different environmental conditions. This will also include environmental risk analysis. It is important to improve our understanding and to obtain better documentation as a basis for ensuring an optimal response if an oil spill incident should happen in the Arctic region.

The basis for this report is results from recent oil spill response research and research need defined through different processes and discussions within the scientific community. This includes also articles / papers and reports that are considered to be important aspects for oil spill countermeasures. Among the references used are:

- Recommendations from Sub-Task 4.2.1.1 “State of the art report on oil weathering and on effectiveness of response alternatives” (Evers *et al.*, 2004), development of existing and potential new concepts for oil spills in sea ice as a platform for further developments and investigations have been suggested.

- Results obtained in previous projects (e.g. INSROP, ARCDEV, MORICE and national RTDs).

- A workshop process according to work done for MMS (U.S Minerals Management Service), refers to SINTEF “Final Report and White paper” (Reed et al., 2002). The “white paper” summarizes the results of a preliminary workshop (Oct., 2002) at MMS Alaska Regional Office in Anchorage. The recommendations from the “white paper” are further considered in this report.

- The Interspill conference, in Trondheim Norway 2004, session 7: “Oil Spill Response in Cold and Ice-covered Water”. This session presented the results of recent oil spill response research in cold and ice-covered waters (Owens, 2004; Mullin, 2004; Buist, 2004; Jensen, 2004; Brandvik *et al.* 2004; Dickins, 2004).

- Oil Spill Response in Ice Infested Waters, (Vefsnmo *et al.*, 1996). The report presents the status on oil spill response in ice- infested waters both for mechanical equipment, dispersants and *in-situ* burning. The recommendations described in report for status on “Oil protection in the northern and Arctic water – ONA” (Løset *et al.*, 1994) are in addition considered in this report. This report is based on earlier studies carried out in Norway.

In addition to the referenced information, meetings and workshops have been arranged within the ARCOP project. Research needs within this area were also discussed during the Statoil International Summit in Trondheim, Norway in 2004. More recently SINTEF presented some papers covering these issues during an Intsok seminar in Houston, USA in March 2005.

There are a number of other research needs, not further discussed in this report, which will be of high relevance for an effective oil spill response in ice covered waters:

- Mapping of weathering properties of relevant oil types (crude oils and oil products) in Arctic areas.
- Studies of water-soluble fractions of relevant oil types and potential biological effects from water-soluble oil components as well as dispersed oil droplets.
- Remote sensing and monitoring of oil under, in, among or on top of ice.
- Operational aspects including operations in remote areas, operations in darkness, operations in harsh and cold climate.
- Improvement and development of modelling tools for:
    - Predicting weathering data of oils and time window for use of different response techniques.
    - Predicting drift and spreading of oils at sea in ice covered waters.
    - Environmental Risk Analysis (ERA).
    - Net Environmental Benefit Analysis (NEBA) and oil spill contingency analysis.
- Alternative oil spill response techniques, like e.g.:
    - Potential use of bioremediation.
    - Use of adsorbents.
- Shoreline cleanup.

This task is part of the ARCOP (Arctic Operational Platform) program, which focuses on the shipping route from the loading terminal at Varandey to Murmansk. Both for this area and other areas in the Arctic as well, long distances to land and also partly remote areas compared to existing infrastructure contributes additional challenges.

2 Research needs for improvement/development of oil spill response concepts

2.1 General

Most of the oil activities in areas with sea ice (shipping, exploration, production etc.) take place in remote areas with long distance to land and without highly developed infrastructure for oil spill response. Low temperatures and little daylight during winter will also give additional challenges to oil spill response operations. The shipping route from Varandey to Murmansk is an example on this. This requires that larger vessels like icebreakers, ice going tugboats and supply vessels being used as a platform for oil spill response equipment. In order to secure short response time it may be necessary that for instance vessels sailing in ice covered waters bring their own response equipment possibly on an assisting vessel (e.g. an icebreaker). Extensive use of fixed wing aircrafts and helicopters may also be necessary for surveillance and monitoring, both for daytime and darkness operations, to bring in additional response equipment and human resources, and to apply dispersants or for ignition in case of *in-situ* burning.

Generally, oil spills in ice are far more complicated to combat compared to oil spills in open waters. Apart from the normally long distances from existing infrastructure, the oil is less accessible in ice-covered waters. The oil can be spilled on ice/snow, in open pools between ice floes, in open channels behind vessels or even under the ice. Traditional use of booms and skimmers can be difficult. However, there are also some advantages with oil spills in ice compared to open waters. The weathering rate is normally much slower for an oil spill in ice. This means that emulsification rate and hence viscosity increase may be slowed down resulting in an increased window of opportunity for use of most response techniques (e.g. the Marginal Ice Zone (MIZ) experiment in 1993, Brandvik *et al.*, 2004). The spreading of oil will be normally also much slower resulting in a large oil film thickness that may be favourable for the oil spill response.

The research needs are presented as short descriptions including an objective, justification/need and scope of work. The aim of this report is to point out the most important aspects for research needs concerning response to oil spills in ice infested waters. The potential for improvement and/or further development and “winterization” of existing equipment, is probably higher than the development of new concepts. Thus a future project for improvement of oil spill response in ice-covered waters should also aim at developing new concepts.

2.2 Mechanical recovery

MORICE recovery system

The main objective for this project was to develop new technology for ice-infested waters. The MORICE scenario included broken ice conditions, concentration low enough to make it possible to move through the ice field with a small workboat, relatively small ice with brash and slush in between, and oil within a wide range of viscosity. After some qualitative small scale laboratory testing of ideas in oil and ice, the stepwise approach included testing of oil recovery and ice processing performance for more carefully designed models in the Arctic Environmental Test Basin at the Hamburg Ship Model Basin (HSVA), followed by design and construction of a full-scale harbor-sized unit comprising oil and ice processing components as well as a catamaran work platform. Ice processing was tested in Prudhoe Bay, Alaska, during freeze-up in October 1999 and in 2000 where ice up to about 35 cm in thickness was processed. The project was finalized in 2002 through testing with oil and ice at the OHMSETT facility in Leonardo, New Jersey (Jensen and Mullin, 2003).

The main idea of the MORICE system (see figure 2.1) is to open up some space between ice pieces so that oil and ice more easily can be separated: A grated belt is lifting the larger ice pieces out of the water. This ice is flushed with water to remove as much oil as possible, where after the ice is re-deployed behind the unit. Together with the small ice and oil going through the belt grating, the flushed off oil and small ice is guided into the recovery area inside the belt. Here a recovery unit picks up the oil and maybe some small ice. After recovery the small ice has to be separated from the recovered product before the oil is stored. The ice processing and oil recovery involved represents a fairly complex "production line", which includes a relatively long processing time for the product (both ice and oil). This was a consequence of a choice made during the development to clean ice as good as possible before it was redeployed.

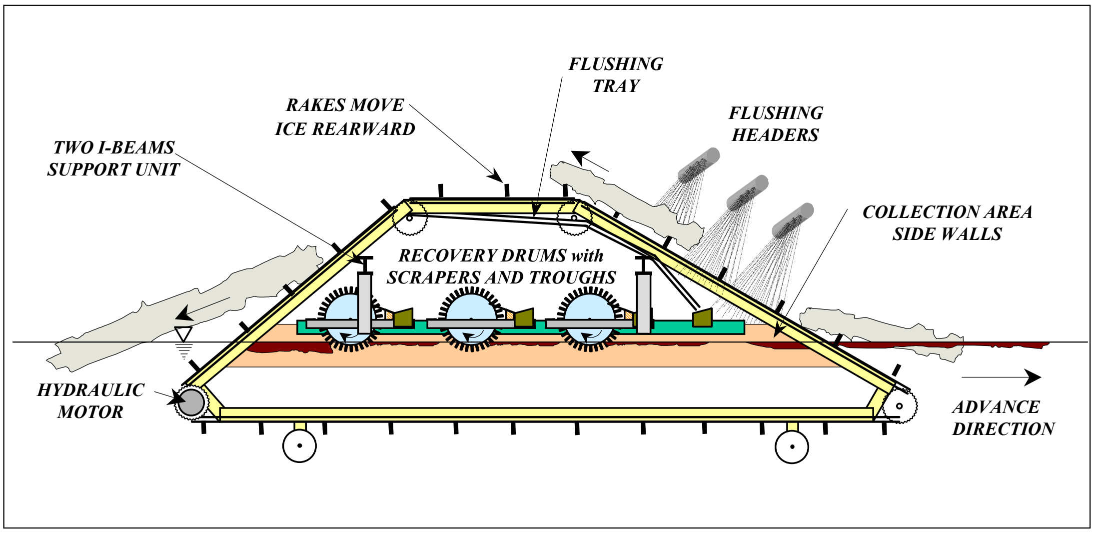

Figure 2.1 MORICE ice processing and recovery principle: Larger ice pieces have oil flushed off while liftedout of the water by the gratedbelt, after which the ice isredeployed behind the unit. Oil and small ice goes through thegrating where a recovery unit picks up the oil, possibly with some ice (Jensen, 2004).

The ice processing and recovery components were sheltered from exposure to wind by a lightweight enclosure or superstructure (see figure 2.2) that could be kept at temperatures around 30° C with an air heater even at outdoor temperatures around –20° C. This solved the problems with icing and freezing.

Figure 2.2 The MORICE work platform during sea trials in PrudhoeBay, Alaska, with a heated enclosure to avoid icing and freezing of equipment (Jensen, 2004).

The concepts comprising the MORICE unit was brought to a stage where it is ready for industrialization. The unit that was built is referred to as a harbor sized unit to indicate the conditions in which this particular size and strength of unit could operate. The choices made regarding cleaning of ice before redeployment very clearly limit the operating speed and hence the encounter rate. For these reasons the developed system would be suited for thorough cleaning of a small spill in ice in harbor conditions.

To combat a larger offshore spill like a tanker accident in ARCOP conditions, the scale of the unit would have to be increased accordingly, both regarding size and strength. The ice processing speed would have to be increased dramatically, which would require a wider and more heavily constructed belt. At the same time the required cleaning of ice probably should be reduced. Still, the basic idea behind the system, to ease the separation of oil from ice by opening up the space between ice pieces, represents an important limitation since the amounts of ice to process could be enormous. Another limitation is the maximum size of ice pieces that could be deflected (lifted) by the unit.

A larger sized unit with its own work platform probably would be too heavy to transport by an assisting vessel to the spill site. For ARCOP conditions we believe that this kind of unit would have to be operated by an assisting vessel, probably somewhat similar to the vibrating unit.

This could be done by positioning the belt in a similar way as it is done on board the present work platform by using hydraulic cylinders to lift and lower the belt. The same deflection and recovery concepts could be applied, but a redesign would be needed together with the increase in dimensions. Most heavy items now installed on board the working platform like pumps,

prime mover, container for recovered product would be located on board the main vessel. This would also facilitate a potential “production line” with separation of ice from recovered product on board the assisting vessel prior to storage.

Mechanical methods dealing with spills in moving broken ice in general have serious limitations, especially for large oil spills. The recovery values will be highly variable depending on a variety of natural conditions and logistics constraints. At the same time, it is very likely that the window of opportunity for mechanical recovery of oil-in-ice could be increased significantly. It is however difficult to imagine that limitations associated with the ice floe size and environmental conditions could be entirely overcome. Nevertheless there are elements for mechanical spill response, which are considered as important to focus on and will be further discussed in this chapter.

2.2.1 Winterizing of existing recovery units for use in ice and cold conditions

Most mechanical recovery methods available are technology developed for open water conditions. Many types of recovery units will not be suitable for recovery in ice at all, while others could probably be improved considerably with relatively simple modifications.

Weir skimmers for instance will in general be blocked by ice very soon. A rotating brush close to the weir (similar to the adapter for the Lamor weir skimmer GT 185, see figure 2.3 a), would allow more viscous oil to pass over the weir, also oil mixed with some smaller ice pieces. This essentially turns the weir skimmer into a brush skimmer, since the recovery is now driven by a rotating brush rather than by gravity flow over a weir. Although the modification described in this example may not make too much of a difference in most recovery situations, it is a step in the right direction. All other important aspects with the skimmer should be examined in turn: Ice processing, pumping/transfer of recovered product, how to reduce the negative influence of ice and low temperature, possibilities for adding heat etc.

The Lamor Arctic Skimmer (see figure 2.3 b) is a crane-deployed system for recovering oil in broken ice and high debris conditions. It incorporates efficient rotating brush wheels for oil separation and recovery, screw conveyors to feed the material toward the offloading pump, and a powerful Archimedes screw pump to transfer the recovered material away from the skimmer.

Reviewing existing concepts systematically searching for modifications that could in turn improve recovery and ice processing, reduce icing, freezing and problems with transfer of recovered products (including ice), would likely open the operational window for most recovery units.

Figure 2.3 a-b *a) Lamor GT 185 modified with rotating brush to improve flow over weir*
b) Lamor Arctic Skimmer LAS 125 W/P

Objective:
The objective is to improve existing recovery units for use in ice and cold conditions.

Justification:
Most exiting recovery units are not made for use in cold conditions and ice. The most cost efficient strategy will probably be to use and modify exiting technology.

Scope of work:

- Go through /review existing recovery units systematically to identify modifications that could improve recovery in cold and ice.
- Carry out necessary modifications in co-operation with the manufacturer, followed by tests under controlled conditions.
- Demonstrate the modified concept in field trials.

2.2.2 Winterizing- Heat suppliers

It is important to protect the recovery units from the heat losses that occur during operations in sub-freezing temperature, especially when combined with wind. The positive effect from sheltering ice processing and recovery units as well as using air heating has previously been demonstrated during the MORICE project. The MORICE system is further described in chapter 2.2.5. Similar protection could be provided also for much smaller equipment since air heaters are produced in very compact units.

Objective:
The objective is to avoid exposure to cold air and protect the equipment from heat losses when used in sub-freezing temperatures.

Justification:
The current technology has shown to be useful to shelter ice processing and protect equipments for icing (MORICE).

Scope of work:

- For each specific recovery unit, identify how to reduce or eliminate exposure to cold wind, and preferably add heat (heat tracing, air heating, hot water, steam).

2.2.3 Mechanical recovery to respond to large oil spills in broken ice

There is a need to develop mechanical response technologies that will make it possible to recover large quantities of oil in dynamic broken ice of various floe sizes. All current technologies are limited by ice size and/or lower recovery efficiency in cold environment and in ice.

Objective:
The objective is to develop mechanical response technologies that will make it possible to recover large quantities of oil in dynamic broken ice of various floe sizes. Develop mechanical response method with features to improve the oil encounter rate and recovery capability and deal with ice of various sizes.

Justification:
All current technologies are limiting by ice size and/or lower recovery efficiencies in cold/ice. Techniques that overcome these initiations are desired.

Scope of work:

- Define ice and spill scenarios to be used in development, avoid being over-ambitious
- Further development of ideas (brain storming):
  - Identify limiting factors.
  - Design and re-design to overcome limitations of existing alternatives.
  - Up-scale existing equipment that is promising.
  - Put together existing concepts in new ways.

    - Look for ideas in other relevant business where handling large volumes/weights are essential (mining, farming, road construction etc).

- As a first step to develop new technologies, identify ways to demonstrate or study the essential elements of ideas.

- Design and build prototypes.

- Demonstrate concept at meso-scale.

- Demonstrate applicability to field situations.

2.2.4 Separation of oil from ice and water

During recovery of oil in ice, considerable amounts of ice (and water) could be recovered together with the oil. Prior to storing recovered product, as much ice and water as possible should be separated to reduce the need for storage capacity and to avoid creating massive ice in the storage. This is one of the most important problems to solve or at least to reduce, and the technology can be developed in laboratories without field trials.

Objective:
The objective is to separate ice and water from recovered product during oil-in-ice recovery, this to reduce the needs of storage capacity and to avoid having solid ice formation in storage containers.

Justification:
It is important to solve or at least reduce the storage capacity of ice recovered with the oil. It will have both an economic and a practical consequence by solving this matter.

Scope of work:
Laboratory experiments:

- Prepare various mixes of oil and ice/water (e.g. oil adhering to the surface of ice, oil frozen into ice, oil mixed with small ice).

- Investigate different ways to enhance separation of oil from ice (and water), with as little use of heat as possible:
    - Warm water flushing (with different temperatures), combined with washing while conveying oil/ice.
    - Steaming while conveying oil/ice through a closed chamber.
    - Hot water bath where oil/ice mixture is fed through (avoid as much melting as possible to reduce heat loss in the water).
    - Heating mixture of oil/ice with a burner (propane, kerosene) to increase temperature and reduce viscosity.
    - Addition of emulsion breakers/dispersant.
    - Breaking ice into small pieces, get access to pockets of oil encapsulated in the ice, prior separation.

- Based on results from basic lab tests, to design, construct and test pilot plant under different operational conditions.

It is believed that separation of oil from ice (and water) can be performed fairly effectively in a production or process line, either open or closed in. This production line will probably need a lot of flexibility in terms of for instance heat added, degree of mechanical handling (washing, breaking ice etc.) in order to work under different conditions and with different types of recovered product.

2.2.5 Further development of the MORICE recovery system

The idea of the MORICE system is to open up some space between ice pieces so that oil and ice more easily can be separated. A grated belt is lifting the larger ice pieces out of the water. The ice is flushed with water to remove as much oil as possible, where after the ice is re-deployed behind the unit. Oil and small ice go through the grating where a recovery unit picks up the oil. The ice processing and recovery components were sheltered from exposure to wind by a lightweight enclosure that could keep a temperature around 30 ºC with an air hater even at outdoor temperatures around -20 ºC. This solved the problems with icing and freezing.

The concept, which comprises the MORICE unit, was brought to a stage where it is ready for industrialization. The unit that was built is referred to as a harbor sized unit to indicate the conditions in which this particular size and strength of unit could operate. The choices made regarding cleaning of ice before redeployment show very clearly limitations regarding the operating speed and hence the encounter rate. For these reasons the developed system would be suited for thorough cleaning of a small spill in ice conditions prevailing in harbors. To combat a larger spill offshore, the scale of the unit would have to be increased accordingly, both regarding size and strength. The ice processing speed would have to be increased dramatically, which would require a wider and more heavily constructed belt. At the same time the required cleaning of ice should be reduced. Still, the basic idea behind the system, to ease the separation of oil from ice by opening up the space between ice pieces, represents an important limitation since the amounts of ice to process could be enormous. Another limitation is the size of ice pieces that could be deflected (lifted) by the unit.

For operation in the ARCOP study area, recovery units for oil-in-ice either have to be large self-supporting units that are strong enough to transit through open water or through ice to the spill site, or the units have to be transported to the site by an assisting vessel (probably a combined ice breaker/ supply vessel).

A large self-supporting unit will be both large and probably prohibitively expensive, which means that for the study area we would recommend to design a fairly large unit to be operated from an assisting vessel, maybe in a similar way that the vibrating unit is operated (see figure 4.2a) This means that the entire unit operated from the side of the assisting vessel would include only the core elements (ice feeder, lifting grated belt, recovery unit, transfer pump). The assisting vessel would provide floatation. All auxiliary equipment like air heater, hydraulic power, and system for separation of oil/ice as well as storage of recovered product is placed onboard of the vessel.

The entire unit would be located on the side of the assisting vessel, stored well above water level when not in use. For operation it would be lowered into the water with built in hydraulic cylinders, but still supported by the vessel.

An alternative modular design of the entire system would make it possible to avoid having the modules stored on the side of the vessel. This would on the other hand require a crane on the assisting vessel that could lift the modules in place for assembly.

2.2.6 The Vibrating Unit (LOIS)[2]

The Vibrating Unit (figure 2.4 a) is a concept that was developed and designed in co-operation by the Finnish Environmental Institute and Lamor Corporation AB to be used in broken ice in a typical navigation channel in Finnish waters.

The special unit is installed on the side of the vessel with its own pivoting hinges and hydraulic lifting system (figure 2.4 b), so that it can easily be lifted for transportation to the scene of the oil spill and then lowered into the water for operation. The transportation position is at 90º angle from the position of operation.

When starting the oil recovery operation, the LOIS equipment is lowered to the water with the aid of the hinge and hydraulic rams (figure 2.4 c-d). This brings the vessel and the LOIS together at their lower edge. The oil that has been under the hull of the vessel is forced aside and passes into the grids of the LOIS for processing. As the vessel moves through the water at a speed of 1-3 knots, the broken ice pieces are pushed under the grids of the LOIS. The grid is oscillating up and down with a stroke of 200 mm and a frequency of about 0.7 Hz. This pushes the polluted ice blocks and debris up and down and the surrounding water then washes the oil off the ice-blocks. As the oil is lighter than water, it rises through the grid inside the LOIS up to the water surface, from where it flows into the LOIS skimmer brushes through an opened side hatch. The pictures are courtesy of Lamor Corporation AB.

Figure 2.4 a-b *a) LOIS attached to the side of MV Linja*
b) Pivoting hinges and hydraulic lifting system

Figure 2.4 c-d *LOIS equipment is lowered to the water with the aid of the hinge and hydraulic rams*

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[2] LOIS: Lamor Oil Ice Separator

Ice to oil ratio is often extremely high for oil spills in ice and the vibrating unit is used in deflecting the ice by submerging while shaking it to improve separation of oil from ice. Ice condition in the ARCOP area are characterized by drifting ice, and implies that unlike in the Baltic Sea, a new ice channel must be broken for every vessel sailing through fairly thick ice. The ice in such a broken channel would be different from the brash ice channels found in the Baltic Sea, and the typical size of ice pieces mixed with oil would probably be larger. Whether the unit will work in ARCOP conditions is difficult to evaluate without testing under real conditions with oil in thicker ice.

2.2.7 Concept ideas developed by FRAMO Engineering AS

FRAMO Engineering AS has worked a lot during the past to come up with technical solutions /ideas how to recover oil spill in ice conditions. To recover oil in ice is a very challenging operation, due the differences in ice conditions, drift and operational conditions. FRAMO do not believe that it is possible to make one machine that can cover all scenarios of oil spill in ice-infested water. Further FRAMO means that the only solution to arctic oil recovery is utilising heavy powerful equipment. Smaller scale equipment cannot be used effectively alone, but utilising the enormous power available on e.g. oil recovery vessel, which can assist other techniques.

The following 6 scenarios give a description of utilising equipment and techniques to recover oil spill in ice conditions. The scenarios are mainly addressed to oil spills from platform, but could also be relevant for oil spills from other sources, e.g. a tanker. Figure 2.3 to figure 2.9 illustrate the technical suggestions and by courtesy of FRAMO Engineering AB. It should be mentioned that FRAMO Engineering AS has a patent application for scenario 6, which describes an oil spill from platform, that drifts under the ice (sub sea recovery).

Scenario 1:
Scenario 1 shows a major spill from platform or other source. Drifting level ice is pushed against and around the platform, and downstream of the platform two recovery vessels will further guide the broken ice on the outside of the oil recovery area. The recovery vessels have a boom in between that collect the oil which is drifting downstream from the platform / spill source. The free-floating skimmer head TRANSREC recovers the oil (see figure 2.5).

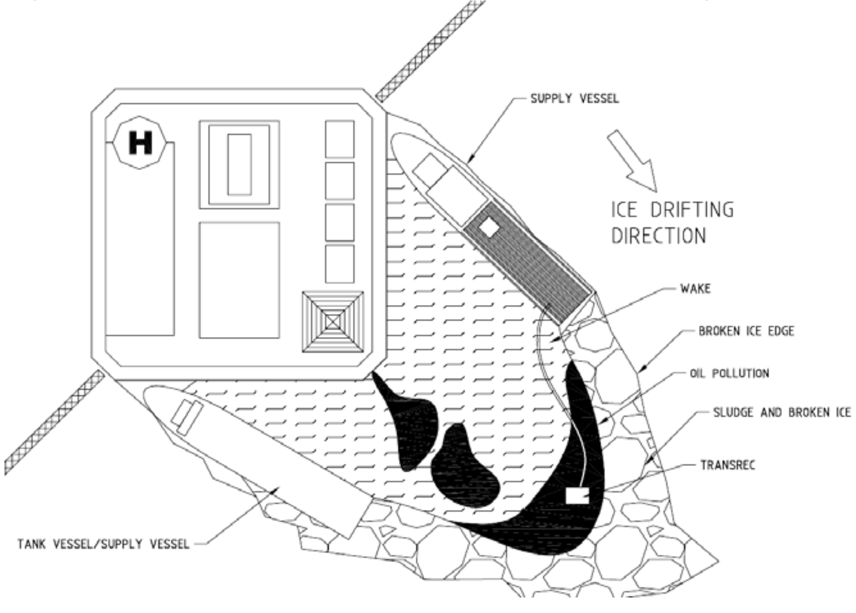

Figure 2.5 Scenario 1: Large oil spill from platform

Scenario 2:
This scenario describes a small spill from a platform or other source. The recovery vessel breaks a trench in the level ice and is drifting with the oil/ice. The oil downstream the platform is recovered with the free-floating skimmer head TRANSREC (see figure 2.6).

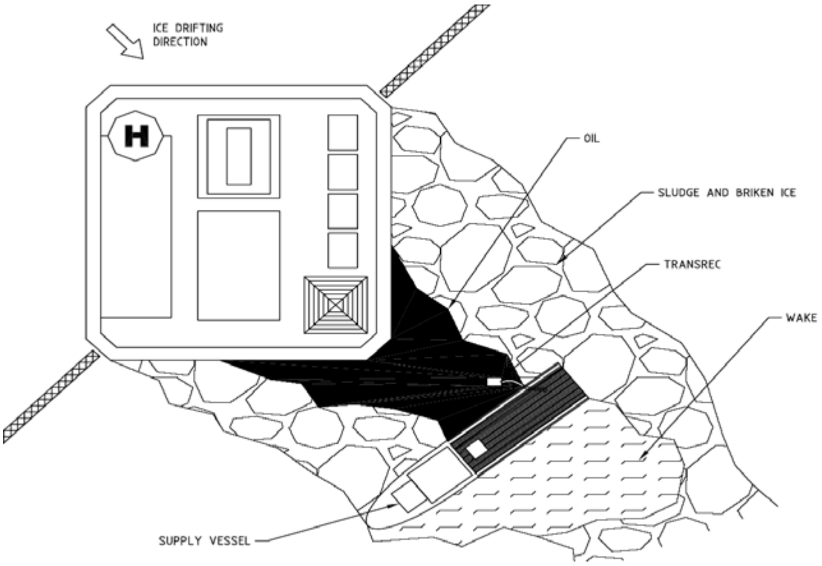

Figure 2.6 Scenario 2: Small oil spill from platform

Scenario 3:
This is a major spill from platform or other source in brash ice and slush. Drifting small ice floes are pushed against and around the platform. Downstream the platform two recovery vessels will further guide the ice on the outside of the oil recovery area. The supply vessel and tank vessel have a boom in between that collect the oil which is drifting from platform / spill source. The free-floating skimmer head TRANSREC recovers the oil (see figure 2.7).

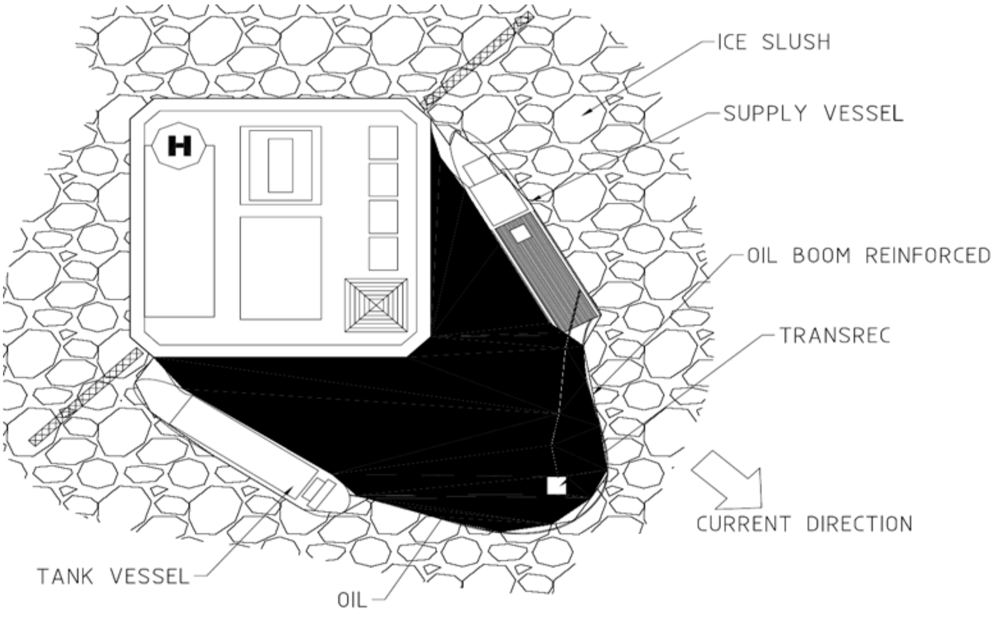

Figure 2.7 Scenario 3: Oil spill from a platform in brash ice and slush

Scenario 4:
The scenario shows a leakage from a tanker, and emergency offloading is carried out. A large fender is used in-between the disabled vessel and the oil recovery supply vessel. The thrusters of the oil recovery vessel are used to generate a V-shaped ice-free skimming area. The oil floating on the surface is trapped due to the V-formation of the vessels and the free-floating skimmer head TRANSREC skims the oil. (see figure 2.8).

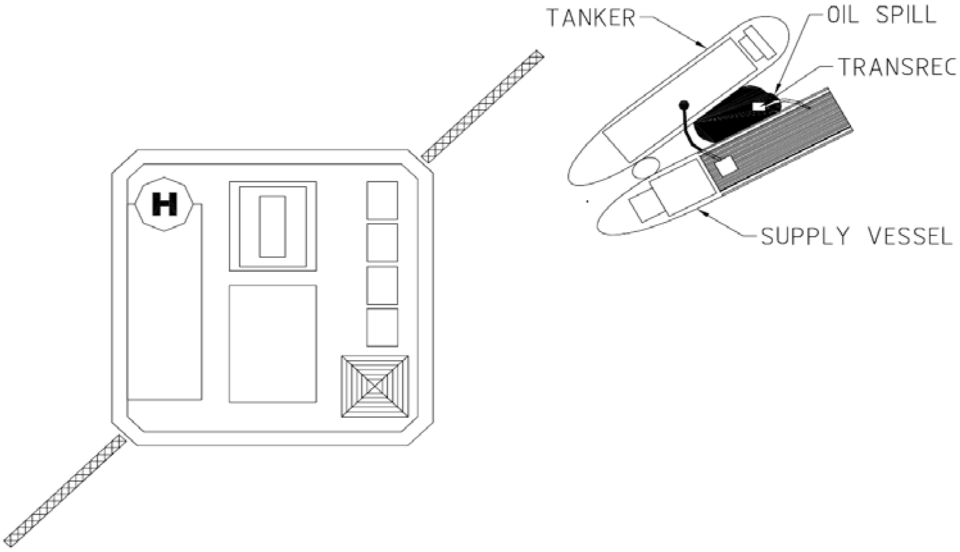

Figure 2.8 Scenario 4: Oil spill from tanker. Emergency pumping from damaged tanker

Scenario 5:
Scenario 5 is an oil spill from a platform that drifts underneath the ice. A hole is cut in the ice and a pump can be lowered through the hole to pump out the oil. This can be done from a variety of holes and the oil will float towards the pump as shown in figure 2.9. One solution can also be to prepare a trench in the ice, so that the oil is drifting. The oil will be trapped in the trench, and the portable pump can pump out the oil.

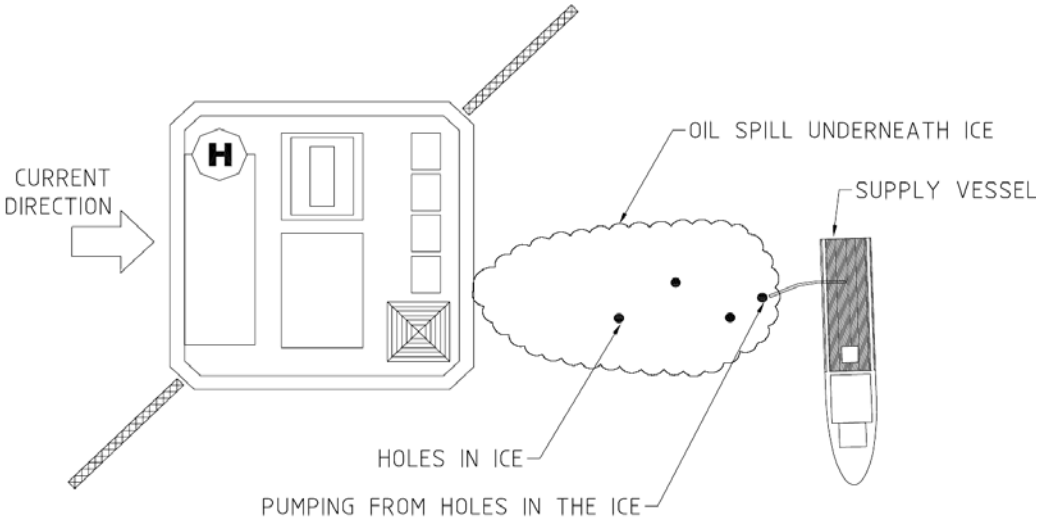

Figure 2.9 Scenario5: Oil spill underneath ice

Scenario 6:

This scenario describes a sub-sea recovery of an oil spill from a platform that drifts underneath the ice. The oil recovery vessel with a moon pool deploys a special designed "underneath ice oil boom" that traps the oil by use of an ROV[3]. The ROV is connected to the TransRec. The ROV is equipped with a suction arrangement and detection system for oil recovery operation (see figure 2.10 and 2.11).

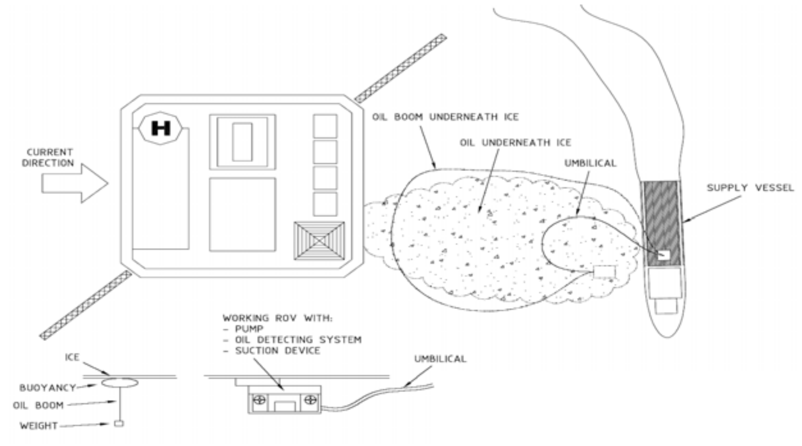

Figure 2.10 Scenario 6: Oil spill underneath ice – sub sea recovery.

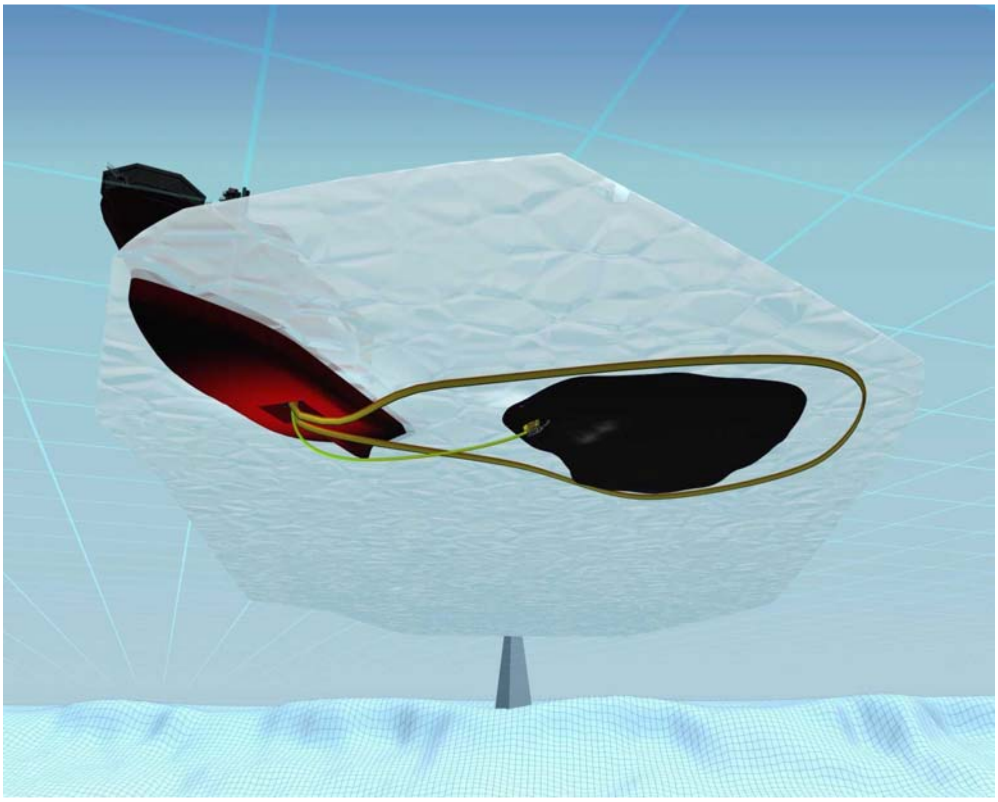

Figure 2.11 Scenario 6: Oil spill underneath ice – sub sea recovery

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[3] ROV: Remote Operating Vehicle

2.3 In-Situ Burning

2.3.1 Introduction

In-situ burning is one of the practical options for removing oil spills in ice-infested waters. The suitability of burning depends on the oil characteristics and the behavior of spilled oil in the environment. As demonstrated through several larger programs in Canada, USA and Norway, *in- situ* burning has the potential to be an effective oil spill response technique in Arctic regions. In general, the technique is effective for thick oil slicks in ice with high coverage. The oil is mainly converted into airborne combustion products and the need for physical collection, storage and transport is strongly reduced. The volume of residue that remains after burning is less compared to the original spill volume.

The use of *in-situ* burning as an oil spill remote technique is not new; the technique has been developed and employed at a variety of oil spills since the late 1960s. Much of the former research and development activity on *in-situ* burning was focused on its application to spills on and under solid sea ice. Most recently, the research has been focused on burning spills in loose pack ice respectively ice floes conditions (Buist, 2004).

The development of fire-resistant oil containment booms beginning in the 1980s offered the possibility of conducting controlled burns in open water conditions. The technology and techniques to conduct *in-situ* burns have maturated in the past few years, and the new generations of fire containment booms represent a mature technology.

In the decade from 1985, exploration in the Barents Sea initiated several programs to develop new or adapt existing oil spill technology to Arctic conditions. In the late 1980s and early stage of 1990s R&D studies were performed by SINTEF in ice-infested water, e.g. different igniters were tested on a wide range of emulsion (oil types, weathering degree). There were also tested limitations for burning of emulsion and the influence of environmental parameters such as wind and waves was investigated. *In-situ* burning tests in open water by use of fire resistant booms with ignition from Heli-torch were carried out.

Today, it is a consensus of the research that *in-situ* burning is a suitable response technique on spill response in broken ice conditions. It have been conducted several small to medium-scale field – and tank experiments to develop and verify the technology. However, there is a limited “window of opportunity” to utilize *in-situ* burns with the presently available technology. This “time window” is defined by the time it takes an oil slick to emulsify. It has been observed if the water content exceeds about 25 % most slicks are non-flammable. It is reported that research is ongoing to overcome this limitation (Buist, 2004). The present situation regarding knowledge and modelling capability concerning Arctic oil spills is limited due to few large-scale field experiments and a lack of knowledge due to oil weathering and the dependence of environmental conditions in a broken ice conditions (e.g. the effect of currents/waves on ignition /burning of emulsion and to determine the limitation of emulsion breakers). Performing systematic large-scale field tests in broken ice will be an important tool to increase and identify the “window of opportunity” for ignition and consequently efficient burning of oil spills in Arctic waters.

Burn efficiency

In-situ burning is particularly suited for use in ice conditions, and might also be the only practical option in some situations when the ice is thick and exposed of high pressure. One of the main advantages of using *in-situ* burning is the significant high oil removal efficiency, which can be obtained. It is reported that removal efficiency for thick slicks can exceed 90 %. Oil removal rates of 2000 m^3/hour can be achieved with a fire area of about 10 000 m^2. The limited demand for logistic support compared to mechanical recovery and use of dispersant favours *in-situ* burning for special situations in the Arctic. During the early state of an oil spill, conditions could be suitable for *in-situ* burning due to the barrier effect of ice and the low weathering state of oil.

Potential benefits:

- Reduces impact of oil on shorelines, sensitive habitats and different wildlife.
- Rapidly consumes oil in the burn.
- Reduces oil storage and disposal problems.
- Reduces the air quality impact of volatile hydrocarbons that would otherwise evaporate and the products from combustion are diluted in the air above.

Potential trade-off:

- Air quality impacts restrict the use for certain locations and conditions to ensure protection of public health caused by-products of burning (e.g. smoke, etc.); this also includes the potential of negative environmental effects caused by the by-products.
- Higher risk associated with sizeable fire and secondary fires that threats human life, property and natural resources.
- Application restricted by equipment and “time window” for effective use.

Requirements for ignition:

In order to burn spilled oil, three elements must be present: fuel, oxygen and a source of ignition. The oil must be heated to a temperature at which sufficient hydrocarbons are vaporized to support combustion in the air above the slick. This temperature is called the flash point. Oil removal efficiency is a function of three main factors: the initial thickness of the slick, the thickness of the residue remaining after extinction and the areal extent of the flame. Oil types, wind speed, emulsification of the oil and igniters strength are factors that affect the ignitability of oil slicks.

2.3.2 In-situ burning as an operational oil spill response for the future

There have been carried out several experiments in the last decades to develop the *in-situ* burning technology. It has been shown that the application of this technology may be useful in cold environment (e.g. ice-infested waters). However there are some aspects that need to be further investigated to define better applicability for use of *in-situ* burning under various oil spill scenarios in the Arctic.

The focus should be addressed to the following subjects:

- Define the potential for use of *in-situ* burning in accordance to effectiveness and limitations to determine a “time window” for operational use (oil type, discharge scenarios, weathering and environmental conditions). To identify parameters with respect to establish a standard methodology to predict the “time window“.

- Igniters and ignition technology and containments: The improvement of both ignition techniques and of fireproof booms will increase “the window of opportunity” for *in-situ* burning. The operational *in-situ* burning in broken ice condition should be tested in Arctic areas, e.g. containments such as new types of fire resistant booms.

- Combination of *In-situ* burning technology with the use of additives to enhance efficiency (e.g. emulsion breakers, herders, absorbance materials). The success of using emulsion breakers in addition with *in-situ* burning depends on oil specific factors based on physical properties of the oil. It is suggested to study different types of oil (e.g. crude oil and refined petroleum products) in under different environmental conditions with a variety of additives.

- Soot reduction / burning residue characteristic. Development of effective methods for recovering burn residue and evaluate existing oil recovery technology.

  This will involve laboratory studies, meso-scale and full-scale field trials verification. Laboratory tests and meso- scale experiments in addition to *in-situ* burns of intentional release of oil of an anticipated response will be necessary to measure the effects of the burn area, waves and movement of oil on the sea surface into a boom or ice barrier. Furthermore the experiments should be focused on oil evaporation and emulsion formation, on ignitability, burn rate, potential for use of emulsion breakers, and oil removal efficiency.

2.3.3 Identify "window of opportunity" for ignition and efficient burning of oil spills in Arctic water

It is proposed to establish a standard methodology to predict the "window of opportunity" for *in-situ* burning. The essential element is the development of a laboratory ignitability assessment test. Results from laboratory experiments should be compared with the results from meso-scale system and verified through field experiments. The data from these tests should be used with existing oil weathering models to predict the "window of opportunity" for use of *in-situ* burning for various types of oil.

Objective:
The objective is to establish how the physical/chemical properties of oil, the oil weathering /emulsification and environmental factors will affect the ignitability and burning efficiency of both crude oil and refined petroleum products for in-situ burning in arctic spill scenarios.

Justification:
When the ice coverage is high (> 8/10), the oil will remain at a relative low state of weathering. Combined with the wave damping effect due to ice, this situation could be suitable for burning.

Scope of work:

- Establish "State of the art" for *in- situ* burning under Arctic conditions.

- Theoretical studies on methods for ignitability and burning efficiency tests under realistic conditions (e.g. methods like Pensky-Martens, Cleveland Open Cup and Cone calorimetric).

- Improve existing methodologies to enhance the ignitability temperature.

- Establish and calibrate laboratory test systems.

- Perform systematic ignitability and burning efficiency laboratory tests with different oil types and refinery products at different weathering degrees.

- Testing of selected oil in meso-scale burning systems.

- Verification of laboratory data in field experiments.

- Development of algorithm to describe and predict the burning of oils as a function of their physical/chemical properties, degree of weathering and distribution in the ice field.

2.3.4 Igniters and ignition technology

In order to burn spilled oil, three elements must be present: fuel, oxygen and a source of ignition. The oil must be heated to a temperature at which sufficient hydrocarbons are vaporized to support combustion in the air above the slick. It is the hydrocarbon vapours above the slick that burn, not the liquid itself. The temperature at which the slick produces vapours at a sufficient rate to ignite is called the *flash point*. The *fire point* is the temperature a few degrees above the flash point at which the oil is warm enough to supply vapours at a rate sufficient to support continuous burning.

Objective:
To improve ignition technology to initiate *in- situ* burns in different scenarios in ice-covered waters and on mud flats.

Justification:
The Heli-torch has been tested extensively in a number of field trials to ignite an oil spill and has proved to be reliable and good igniters. However, it is dependent on helicopters, which can be difficult in remote areas, due to long distances. It is therefore a need to look into other options to ignite an oil spill and also the potential use of additives to promote ignition.

Scope of work:

- Hand held igniters that can be shoot from a vessel or even from the ice. These could be based on a variety of fuels and should have built in a delayed ignition to allow the igniters and the slick to stabilise prior to ignition.

- Potential new ignition concepts and application of ignition technology. If *in- situ* burning should be a fully operational option in remote areas, ignition technology should be made available as extra equipment on supply vessels and icebreakers.

- Development and description of potential ignition promoters to increase the ignitability of the slick or spreading of flame over the surface of a slick.

2.3.5 Operational in-situ burning in broken ice conditions

New types of fire resistant booms (actively cooled) have been developed and tested in the past few years, but none have been tested in Arctic conditions. Most *in-situ* burning projects have been conducted in small-medium test tanks. At the same time there are certain tactics and techniques that only can be accomplished through an in-the-field exercise.

Objective:
The objective is to conduct full-scale operational *in-situ* burns in broken ice conditions. The focus could be on the types of broken ice typically found in the near shore areas where oil exploration activities are taking place or are planned.

Justification:
It is important to conduct *in-situ* burning field tests in open water since the most *in-situ* burning projects only have been tested in small-medium test tanks. Information and results from these

experiments will be used to justify scientific decisions on the suitability of in situ packages for the planned operations.

Scope of work:

- Conduct *in-situ* burning experiments with actively cooled booms in ice-infested waters to determine their performance. Testing both, inside and outside the ice edge, should be included.

- Develop effective methods of recovering the burn residue or evaluate the existing oil recovery technology for this purpose.

2.3.6 Use on shorelines and mudflats

Objective:

Assessment of the potential of *in-situ* burning as a countermeasure on shorelines and mudflats including also potential ecological effects from such application.

Justification:

In Norway today, *in- situ* burning is primarily described as a response option in ice-covered waters. However, it could also have a potential as a countermeasure on remote shorelines or inaccessible mudflats in Arctic areas (Tundra).

Scope of work:

- Study the ignitability and burn effectiveness on shorelines and mudflats.

- Potential ecological effects from *in situ* burning.

- Potential for treatment or removal of burn residue and potential ecological effects.

2.4 Use of dispersants

2.4.1 Introduction

There is a potential for use of dispersants in cold-water environments with ice. For obtaining an effective dispersant operation in Arctic areas, it is important to evaluate the following critical parameters:

- Access (contact) of the dispersant to the oil.

- Sufficient mixing energy for the dispersion process.

- Oil properties at low temperature (weathering degree), with special focus on viscosity and *pour point*.

- Dispersant performance and properties under the relevant conditions (salinity of sea water, temperature, oil type).

Figure 2.12 indicates some potential oil spill scenarios in ice-covered areas. With increasing ice coverage it becomes more challenging to fight the oil spill with dispersants, as it is for mechanical recovery as well.

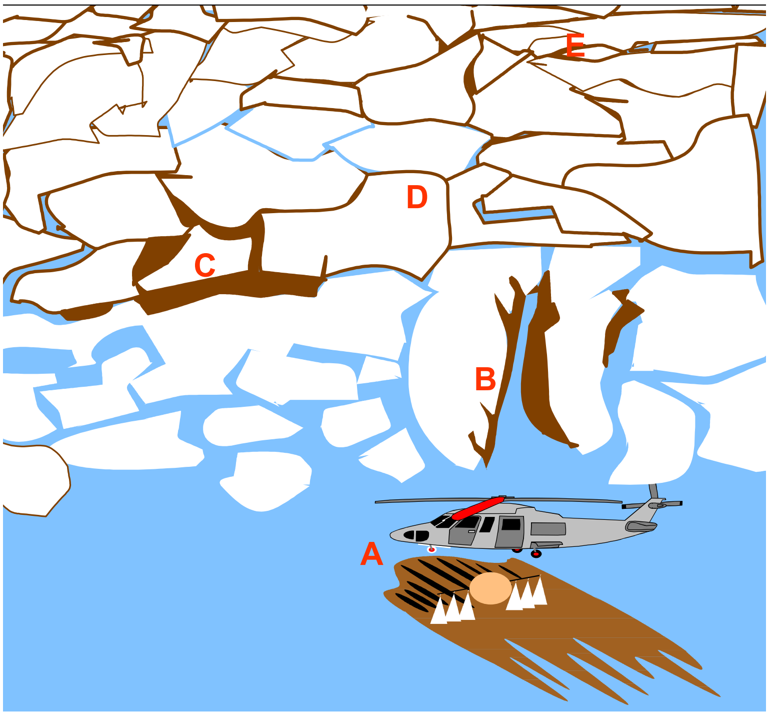

Figure 2.12 Potential oil spill scenarios in ice-covered areas. A: Oil in open and cold water outside the ice; B: Oil at the ice edge; C: In low ice coverage (< 50 %); D: In high ice coverage (> 50 %); E: melting pools on ice.

The application of dispersants has been studied extensively for over 30 years (Owens, 2004) and dispersants have been used successfully in many actual oil spills. However, little laboratory and fieldwork has been performed with dispersants and oil in ice and the potential for use of dispersants under arctic conditions has been little demonstrated.

A better understanding is needed regarding application of dispersants in various scenarios under Arctic conditions. Limitations for the applicability of dispersants in cold and/or ice covered waters have to be defined. Capabilities of the dispersants should be investigated with respect to disperse various oil in cold water effectively with different levels of mixing energy, in particular when brash ice and slush are present.

The key concerns for use of dispersants in cold environments with ice have been centred on the lack of natural mixing energy, due to the damping effects of the ice, and the tendency for oil to become viscous at low temperatures. The use of icebreakers or other vessels to introduce the necessary mixing energy, in combination with dispersants leads to longer retention of viscous oils, and consequently could lead to the fact that dispersants become a practical response option for oil spills in ice. However, research in this area is at an early stage and much more effort needs to be done before a definitive answer is available (Dickins at al., 2004).

Earlier studies carried out in Norway (e.g. ONA report 1995/ AKUP report 1996) conclude that the use of dispersants can be a suitable response method, either as an independent response method or in combination with e.g. mechanical oil recovery, to a number of scenarios in Arctic waters, both in open-water and in ice coverage up to around 50 %. Application could be performed from aircraft /helicopter /boat on oil spill in open water (outside the ice edge), from e.g. helicopter or boat (use of artificial mixing energy) in relative open ice conditions (low ice coverage). Helicopters should be used preferably when oil is spilled in melt pools or areas of high ice coverage. The dispersion rate is enhanced by oil drifting into open/turbulent water. Figure 2.13 illustrates the various application methods for different environmental conditions (open water – marginal ice zone – melting pools).

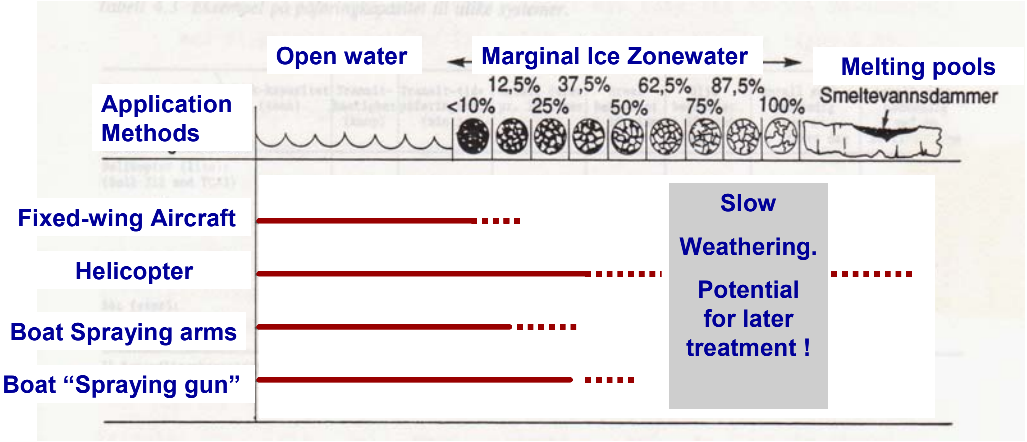

Figure 2.13 Potential application methods different environmental conditions (open water – MIZ – melting pools)

2.4.2 Improved documentation of effectiveness

Objective:

Provide better documentation on effectiveness of the present generation of dispersants on various oils (crude and bunker oils) under relevant weathering degrees and different Arctic conditions.

Justification:

In Norway, there is a fairly good documentation on the effectiveness of selected dispersants on most crude oils in production. However, the knowledge is insufficient regarding the use of dispersants at low temperatures, low salinity and the presence of ice.

Scope of work:

- Study the influence of low air temperatures (below freezing point) by use of dispersants. Low temperatures will cause a viscosity increase of the dispersant that can cause problems with spraying through nozzles.

- Study the influence of low seawater temperatures by use of dispersants. Low temperatures will cause a viscosity increase of the oil. Oils with high pour points may have a tendency to solidify at low temperatures. This may have a significant influence on the effectiveness by use of dispersants.

- The effectiveness of dispersants is dependent on the seawater salinity. Dispersants developed for use under "normal" salinity conditions (around 3,5 %) can show a dramatic drop in effectiveness when water salinity is low. This phenomenon should be taken into account when dispersants are used in river estuaries, where normally the water salinity is less than in the ocean. Studies to find the best products under different salinity conditions should be an overriding activity. The development of new and more specialized products could be another activity.

- Study of dispersant effectiveness in various scenarios with different ice coverage.

The above mentioned task should be performed as a combination of literature study, laboratory experiments and meso-scale tank experiments with the option of verification in the field.

2.4.3 Development of dispersant for long-term retention in viscous oils

Objective:
Development of a new type of dispersant formulated for long-term retention to assess ability of dispersant in order to remain with the oil as the ice moves from low energy (internal pack) to a higher energy (ice margin) environment.

Justification:
Longer retention time for dispersants by viscous oil will improve the time window regarding increased effectiveness of the dispersants.

Scope of work:

- State of the art study on dispersants formulation to explore the potential.
- Formulation and laboratory testing to develop new type of dispersant.
- Study the effectiveness of the dispersant whether it is possible to achieve permanent dispersion in the water column with ice present.
- Meso-scale tank and field-testing and verification.

2.4.4 Extended time window for use of dispersants

Objective:
To look further into the potential for spiking emulsion inhibitors and pour point depressant chemicals into various bunker oils qualities and various paraffinic / waxy crude oils, in order to extend the time window for use of dispersants. This is a project that has been partly initiated through the DISCOST[4] project at SINTEF and a project supported by the Norwegian Research Council.

Justification:
The effectiveness by use of dispersants on paraffinic / waxy crude oils with high pour point and heavy bunker fuel oils can often be low, especially at low temperatures. The use of chemicals for inhibiting emulsion formation and/or wax precipitation can improve the effectiveness and time window for use of dispersants.

Scope of work:

- Literature review / preliminary evaluation of the concept / planning of experimental design

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[4] DISCOST: "**Dis**persant use in **Co**astal waters and **S**horeline **T**reatment" is a proposal program (2002) which consists of several tasks.

- Bench-scale laboratory testing:
    - Static effectiveness screening of chemicals.
    - Effect of concentration, temperature, oil types.
    - Leaching tendency of chemicals to aqueous phase.

- Meso-scale flume testing, to follow the long-term difference in behaviour between treated and non-treated oils.

- Field tests. The final phase should be full-scale field verification.

2.4.5 Optimize dosage needs for various oil types

Objective:

To find the optimal dosage (dispersant to oil ratio = DOR) for various oil types (crude oils and oil products) under different Arctic conditions found in the Barents Sea.

Justification:

The optimal dosage (DOR) can vary from oil type to oil type. An optimal DOR is important for the maximum effectiveness and for a cost – effective use of dispersants.

Scope of work:

- Standardized laboratory testing with different dosages of selected dispersants on different crude oils (or groups of crude oils) and a selection of oil products.

- Meso-scale testing and field verification.

2.4.6 Application technology

Objective:

Testing and further development of equipment for application of dispersants on oil in ice with different ice coverage and under low temperatures.

Justification:

Low temperatures will require application equipment that can operate under the harsh climate that can be encountered in the Barents Sea region in wintertime. The requirements for application equipment may be different for spilled oil in open water to oil trapped in ice of dense ice coverage.

Scope of work:

- “Winterization” of application equipment to be used in cold and harsh environments.

- Testing and further development of vessel based application equipment for use in ice-covered waters with varying ice coverage.

- Testing and further development of air based application equipment (helicopter and fixed wing aircraft) for use in ice-covered waters with varying ice coverage.

2.4.7 Artificial turbulence

Objective:

The objective should be to identify and test methods in order to introduce energy to start a dispersing process in low energetic conditions in ice covered waters.

Justification:

To start a dispersing process after application of dispersants to an oil slick a minimum of energy (or turbulence) is normally required. In the marginal ice zone and in areas with high ice coverage the energy (turbulence) is normally very low. In such areas artificial turbulence may be required to be able to start the dispersing process.

Scope of work:

- Literature study to identify different options for creating artificial turbulence.
- Laboratory and meso-scale testing with different energy input to find the minimum energy required starting the dispersing process.
- Evaluate the most promising options with respect to effectiveness in the field and at the same time study the behavior of the dispersed oil droplets under the ice.

2.4.8 Injection of dispersants from the sea bed

Objective:

Study the potential for injection of dispersants from seabed into an underwater blow out.

Justification:

In case of an underwater blow out in ice covered waters the oil can be easily trapped under the ice and can be almost inaccessible regarding traditional countermeasures. A potential injection of dispersant into the blow out at the seabed could lead to a dispersion of the oil into the water column and reducing the trapping of oil under the ice. Desk studies have demonstrated that such injection concept is feasible.

Scope of work:

- One option could be to inject the dispersant directly into the oil/water stream directly behind the blow out point.
- A down-hole injection concept could be a second option. In this case the dispersant could be injected into the well flow through the annulus.
- Testing of both options in a laboratory set up with an artificial column and possibilities for sampling and measurements:
    - Measurement of the effectiveness of mixing of dispersant into the oil phase by the two options.
    - Measurement of potential reduction in oil droplet size as a result of dispersant addition.
    - Sampling and analysis of physical-chemical properties of the oil without and with addition of dispersant.
- Possible field verification based on the experience from the DeepSpill experiment performed in Norway in 2000 (Johansen et al., 2003).

2.4.9 Fate and degradation of dispersed oil in cold and ice covered waters

Objective:
The objectives will include both, optimisation of experimental design and generation of data to determine the time-related fate, processes and degradation of chemically dispersed oil in the water column in cold and ice infested waters. It will be important that the fate data of chemically dispersed oils are quantifiable compared to natural (mechanical) dispersal and also comparable with similar data obtained from more temperate areas.

Justification:
The fate of dispersed oil (both chemically and natural) in the water column by use of dispersants can be very different in cold and ice covered waters compared to more temperate areas. Data from such a task should be compared to similar data from more temperate areas. The principle behind the use of dispersants is that the oil droplets formed are much smaller that what we find from mechanical dispersion. Small oil droplets disperse faster and have a lower rising velocity compared to large droplets. These effects (in addition to turbulence) cause the oil droplets to remain in the water column. The use of dispersant decrease the interfacial tension between oil and water, the water /oil surface as well as the degradation by bacteria will increase. This has to be studied and verified also for Arctic areas. The water temperature may be an essential parameter.

Scope of work:

- Establish experimental design.
- Determination of droplet size and distribution.
- Interaction with ice.
- Analyses of water-soluble oil components (WAF = Water Accommodated Fraction).
- Comparison of depletion processes in mechanically and chemically dispersed oils.
- Determination of fate data related to weathering processes.
- Determination of depletion processes for detection of possible persistence of metabolites.
- Simulation of a field situation - experiment in flow-through system.
- A need for controlled tank experiments followed by field verification.

2.4.10 Biological effects in the water column in ice covered waters and at the ice edge

Objective:
To quantify the effect of chemically dispersed oil relative to mechanical dispersed oil with respect to both short-term (acute) effects and long-term effects on species of different tropic levels, in ice-covered waters and at the marginal ice zone.

Justification:
Existing model tools can predict the spreading and drift of oil droplets and water-soluble oil components in the water column by use of dispersants. However, which concentration levels

have the potential to cause biological effects in the water column is still a matter of discussion. There is a need to provide such data for ice covered waters as well as more temperate regions.

Scope of work:

- Establish exposure systems (flow through) and analysis for realistic simulations.
- Short term acute tests – lethality tests.
- Long term effects to WAF and oil droplets from naturally and chemically dispersed oil.
- Establish dose/response relations of long-term effects and acute exposure.

3 Conclusion

The aim of this project has been to identify research needs for improvement and further development of oil spill response concepts for the use in ice-infested waters. The project is part of the ARCOP (Arctic Operational Platform) program, a research and technology development program with the overall objective to form an operational platform for development of petroleum transportation in the Arctic region.

The core issue in ARCOP is the transportation of oil from a terminal at Varanday to the European market. This could be done either by tankers going all the way from Varanday to the western Europe, or to some reloading terminal, for instance in the Murmansk area. We are talking about year round shipping, which means that the transport will go through areas with ice during the winter months. Sea transportation of oil and gas products from the Pechora and Kara Sea region as well as oil/gas exploration in arctic waters will increase the risk of oil spills in this highly vulnerable environment. Most of the research needs highlighted in this report are valid both for the part of the transportation route from Varanday to Murmansk covered with ice during winter and spring as well as other ice covered Arctic areas.

To establish an efficient oil spill contingency for winter/spring conditions in Arctic areas requires improvements of existing methods and developments of new oil spill response concepts. Up to date, there has been a lack of field trials for operational testing of combating techniques related to the Arctic. Three main subjects have been discussed in this report: mechanical recovery, *in-situ* burning and use of dispersants. Remediation technologies and shoreline cleanup are also important aspects when discussing countermeasures in cold environment, but these issues are beyond the scope of this report.

The following recommendations are given for the different areas of research and development:

Mechanical recovery:
Due to the low temperatures normally found in the Arctic and the presence of ice, existing response equipment needs to be modified to operate under harsh conditions (winterization). This may include improved ice processing, reduction of icing/freezing (heat supply), transfer of recovered products (including ice), and separation of oil from ice.

The MORICE recovery system is one of the most recent developments for mechanical recovery of oil in ice and has a potential for further improvement and commercialising. The same is also valid for the Lamor Oil Ice Separator (vibrating unit), which is also a recent development.

FRAMO Engineering AS has described some technical solutions for oil spill scenarios around oil installations and vessels. This is by use of existing booms, powerful vessels and weir skimmers with high pumping capacity. They also describe a concept for recovery of oil underneath the ice. These ideas should be further evaluated and there may be a need for winterization of the equipment.

***In-situ* burning**
In-situ burning may have a considerable potential for its application in ice conditions and may offer the only practical option for removal of surface oil in such situations. Much research, including field activities, has been done in this field in USA, Canada and in Norway. In this report the importance of identifying the “window of opportunity” for ignition and efficient burning of oil spills in the Arctic has been stressed. The “window of opportunity” will vary between different crude oils and oil products. Based on a systematic laboratory testing and field validation it is suggested to include the “window of opportunity” for burning as a standard prediction from weathering predicting models.

Ignition technology is another important aspect that needs to be looked into. When operating in remote areas it is necessary to have igniters that do not necessarily rely on aerial ignition.

Even if *in -situ* burning has the largest potential in ice; it should also be evaluated as a potential response option for remote shorelines and inaccessible mudflats in Arctic areas.

Use of dispersants

There is also a potential for use of dispersants in cold-water environments with ice. For obtaining an effective dispersant operation in Arctic areas, it is important to evaluate the following critical parameters:

- Access (contact) of the dispersant to the oil.
- Sufficient mixing energy for the dispersion process.
- Oil properties at low temperature (weathering degree), with emphasis on viscosity and pour point.
- Dispersant performance and properties under the relevant conditions (salinity of sea water, temperature, oil type).

Recent promising results in tank tests sponsored by industry have spurred a re-examination of dispersants as a potential strategy for certain oil-in-ice scenarios (Mullin, 2004). The use of icebreakers or other vessels to introduce the necessary mixing energy, in combination with dispersants formulated for longer retention by viscous oils, could lead to dispersants becoming a practical response option for oil spills in ice. A combination of systematic laboratory and basin studies and field validation is needed to make dispersants use a practical countermeasure in ice-covered waters.

It is important to improve the documentation of the effectiveness of dispersants at low temperatures (in water and air), at low water salinity and the presence of ice. This may include a screening of existing products, potential development of new products and to find the optimal dosage for various oil types.

Application technology is another key element. Aerial application, vessel application and the potential injection of dispersants from the seabed should be further explored. Due to the wave damping effect by the presence of ice means of creating artificial turbulence should be further investigated.

The potential ecological effects caused by the dispersed oil droplets and the water-soluble oil components often cause public concern. The potential effects should be studied both for ice-covered waters as well as at the ice edge. The fate and degradation of the dispersed oil should also be further studied.

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