Research to Improve Oil Spill Response in the Arctic – A Joint Industry Programme

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Abstract
For more than 50 years, the oil and gas industry has funded and conducted research to improve oil spill response technologies and methodologies with industry, government, academia, and stakeholders jointly involved. This research has included hundreds of studies, laboratory and basin experiments and field trials, specifically in the United States, Canada and Scandinavia. Recent examples include the SINTEF Oil in Ice JIP (2006-2009) http://www.sintef.no/Projectweb/JIP-Oil-In-Ice/Publications and research conducted at Ohmsett - The National Oil Spill Response Research and Renewable Energy Test Facility www.ohmsett.com/activities.html. This sustained and frequently collaborative effort is not commonly known and recognized by those outside the field of oil spill response.

To build on this existing research and continue improving the technologies and methodologies for arctic oil spill response, nine international oil and gas companies (BP, Chevron, ConocoPhillips, Eni, ExxonMobil, North Caspian Operating Company (NCOC), Shell, Statoil, and Total) are working collaboratively in the Arctic Oil Spill Response Technology - Joint Industry Programme (JIP). The goal is to advance arctic oil spill response strategies and equipment as well as to increase understanding of potential impacts of oil on the marine environment. The programme is coordinated by an Executive Steering Committee comprising representatives from each company. The International Association of Oil and Gas Producers (OGP) is providing project management expertise. The world's foremost experts on oil spill response, development, and operations from across industry, academia, and independent scientific institutions are being engaged to perform the scientific research.

The JIP has completed phase one that included technical assessments and state of knowledge reviews in the following six areas: dispersants, environmental effects, trajectory modelling, remote sensing, mechanical recovery, and in situ burning (ISB). Nine research reports are available on the JIP website (www.arcticresponsetechnology.org) that identified and summarized the state-of- knowledge and regulatory status for using dispersants, remote sensing and ISB in the Arctic. Phase two activities are now underway including laboratory, small and medium scale tank tests, and field research. Eleven projects are in progress ranging from dispersant effectiveness testing; modelling the fate of dispersed oil in ice; assessing the environmental effects of an arctic oil spill; advancing oil spill modelling trajectory capabilities in ice; extending the capability to detect and map oil in darkness, low visibility, in and under ice; improving efficiency of mechanical recovery equipment in ice; chemical herder fate and effects; and expanding the 'window of opportunity' for ISB response operations. This paper presents recent JIP progress.

Introduction:
Response options in the Arctic vary depending on the time of year. Major operational challenges for arctic oil spill response are: remoteness, low temperatures, seasonal darkness, and the presence of seasonal sea ice The selection of one or more strategies to deal with a spill in an arctic environment will depend upon a variety of factors, including the size and type of spill, local weather and sea conditions, and the presence, concentration and characteristics of ice. Companies can respond rapidly and effectively with the aid of a Net Environmental Benefit Analysis (NEBA) to deploy the most effective strategies to minimize the impact of a spill for any given scenario. Decisions on response options depend on the spill conditions at the time and the relative risks to response personnel and the environment. The flexibility to use a broad range of response options, as conditions change, is essential to mounting the most effective response possible.

Arctic Oil Spill Response Technology - Joint Industry Programme:
The oil and gas industry has made significant advances in being able to detect, contain, and cleanup oil spills in arctic environments (API 2012). Ongoing research continues to build upon more than fifty years of examining all aspects of oil spill preparedness, oil spill behaviour and options for oil spill response in the Arctic marine environment. To build on existing research and improve the technologies and methodologies for arctic oil spill response, members from the IPIECA-Oil Spill Working Group, Industry Technical Advisory Committee (ITAC) and the American Petroleum Institute-Emergency Preparedness and Response Program Group formed a joint committee in 2009. The committee's task was to review the oil and gas industry's prior and future work scope on prevention and response to oil spills in ice, to identify technology advances and research needs in industry

preparedness, and prioritize identified issues. One outcome was the recommendation to establish the Arctic Oil Spill Response Technology - Joint Industry Programme (JIP) that would undertake specifically targeted research projects identified to improve industry capabilities and coordination in the area of arctic oil spill response.

The JIP research is focusing on expanding industry knowledge of and capabilities in arctic oil spill response in Dispersants, Environmental Effects, Trajectory Modelling, Remote Sensing, Mechanical Recovery, and ISB. Recognized subject matter experts with years of experience in oil spill response research and operations lead Technical Working Groups (TWGs), managing each research area. All research projects are being conducted using modern protocols and proven scientific technologies, utilizing the best and most appropriate available researchers, consultants, and laboratories.

Project 1 - Fate of Dispersed Oil under Ice

One of the requirements for efficient dispersion is adequate mixing in the water column allowing for a cloud of dispersed oil to rapidly dilute to very low concentration. A key parameter for stable dispersion is the level of turbulence required to keep dispersed oil entrained in the water column. In the Arctic, ice cover dampens energy input from the wind into the ocean (SL Ross Environmental Research Ltd., 2010). This dampening may cause turbulence under the ice to be lower compared to an open ocean environment. Existing numerical models can determine how quickly dispersed oil plumes will rise on the basis of information on ambient turbulence conditions, dispersed oil droplet size distributions, and dispersed oil densities. For these models to predict dispersed oil behaviour under ice, improved understanding of the natural turbulence under a range of ice roughness conditions is required.

The overall goal of this research project is to provide critical information in support of dispersants use in ice-covered marine environments and develop a tool to support contingency planning decisions with respect to dispersant use. The aim is to provide additional evidence to support dispersant use and decision making in ice-covered waters and to determine optimal operational dispersion criteria. The primary research objective is to develop a detailed numerical model that predicts the potential for a dispersed oil plume to resurface and reform a new slick under the ice and then run the model with varying ice concentrations, release types, environmental conditions, oil types, and levels of turbulence. The model is being designed to evaluate whether or not dispersed oil droplets formed under continuous or concentrated ice could resurface under the ice to form a significant accumulation within two days. The first phase determined what data already exists to support model development. The a second phase is focusing on gathering the additional data required to run and validate the model and then modelling surface and subsurface dispersant use scenarios.

Progress: SINTEF, Trondheim, Norway is the contractor for this project. The phase one report entitled:" Fate of Dispersed Oil Under Ice – Literature Review" provides a summary of background information on the state of knowledge concerning under-ice turbulence and methods for obtaining additional data as necessary to allow the development of a reliable model to predict whether oil droplets could surface within a two day period based upon an initial oil droplet size distribution. Phase two research is about to get underway that includes flume tank turbulence experiments, under Ice turbulence and dye study field experiments, experiments to determine the dispersion of oil with propeller wash, and development of droplet rise tables. The JIP is also working to collaborate and leverage data collection with ongoing efforts in the Barents Sea and the Beaufort Sea Marginal Ice Zone.

Project 2 - Dispersant Testing under Realistic Conditions

Researchers have examined dispersant effectiveness in cold waters with sea ice at both laboratory scale and in wave basin tests using a variety of oils. It has been demonstrated that dispersants can generally be more than 80 percent effective in near-freezing waters. Research has also demonstrated that inorganic mineral fines in turbid coastal waters function naturally to form oil mineral aggregates (OMA's) that can remove oil from contaminated shorelines. The Department of Fisheries and Oceans, Canada and the Canadian Coast Guard demonstrated through field research that streams of mineral fines slurry combined with mixing energy from vessel propeller wash promoted rapid OMA formation and dispersion of oil slicks in ice (SL Ross Environmental Research Ltd., 2010). Use of chemical dispersants and/or mineral fines provides a response option with high encounter rates, high effectiveness, lower manpower requirements, and greater responder safety than mechanical response. Further, mineral fine treatment may be suitable for use on spills in freshwater.

The overall goal of this research project is to provide additional evidence to support dispersant use in ice-covered waters. The primary objective is to define the operational limits of dispersant and mineral fines in arctic marine waters with respect to oil type, oil viscosity, ice cover (type and concentration), air temperatures, and mixing energy (natural, water jet and propeller wash). A second objective is to identify the regulatory requirements and permitting process for dispersant and mineral fines use for each arctic nation/region. This project is being conducted by individual tasks on a phased approach.

Progress: SINTEF, Trondheim, Norway is the contractor for this project. Three tasks are complete and reports available on the JIP website. The first report “Dispersant Testing Under Realistic Conditions: State of the Knowledge Review**”,** summarized the scientific literature and identified previous research of dispersant effectiveness under arctic conditions. Important parameters assessed were oil type (naphthenic, asphaltenic, paraffinic, waxy crude or fuel oil), oil viscosity, oil weathering degree, dispersant type, dispersant to oil ratio, salinity, ice coverage, mixing energy, and temperature (Lewis, 2013). The second report “Test Tank Inter-Calibration for Dispersant Efficiency” was to determine energy conditions and develop consistent test protocols between the CEDRE, SINTEF and SL Ross meso scale flume basins prior to the start of the dispersant effectiveness experiments (Faksness et al 2013). The third report “Dispersant Use in Ice Affected Waters: Status of Regulations and Outreach Opportunities” identified and summarized the regulatory requirements and permitting process for using dispersants and mineral fines for each arctic nation (SEA 2013). The main findings from the reports are:

- Dispersants can work in the Arctic and will, under certain conditions, be more effective in the presence of ice than in open water.
- In addition to increasing effectiveness, the presence of ice can increase the time window within which dispersants can be used effectively.
- Except for the UK and the US there is generally an absence of national policies and procedures to approve the use of dispersants during an incident.
- Some countries, however, have good regulatory models established for dispersant use.

Mesoscale flume tank experiments have been started in Canada, France, and Norway that will run through June 2015 to establish boundaries to define dispersant effectiveness and dispersant effectiveness experiments with natural mixing energy. The test plan calls for 75 dispersant and 45 OMA experiments to be conducted. Five oils will be used, oils will be weathered 18 hours, four dispersants and OMA’s, two DOR’s, three energy levels (low, high, propeller wash), two levels of ice coverage, and three salinity levels (5,15, and 35 ppt. Research experiments on the use of polyethylene blocks to improve dispersant effectiveness test repeatability are also being conducted. Upcoming tasks include laboratory and mesoscale flume tank experiments to evaluate dispersant effectiveness with open water conditions, with propeller wash, and after oil or oil-dispersant mixtures have been frozen in or on ice.

Project 3 - Environmental Impacts from Arctic Oil Spills and Oil Spill Response Technologies

The overall goal of this research project is to improve the knowledge base and stakeholder acceptance for using "Net Environmental Benefit Analysis" (NEBA) for response decision making and ultimately gain stakeholder acceptance of the role of environmental impact assessment in oil spill response plans and operations. Due to the fundamental role of comparing the effectiveness and impacts of different response options in NEBA, the information base needs to address both the acute and long-term effects of spilled oil as well as the impacts of various response options (e.g., natural attenuation, surface/subsea applied dispersants, in situ burning, etc.) on Arctic ecosystems. Review and tabulation of published measured effects (e.g., toxicity thresholds and recovery times) is anticipated to be an important part of this project which is being conducted in three phases:

1. Perform a comprehensive review on the environmental impacts of arctic oil spills and from the technologies used to respond to such spills and identify research activities to improve the knowledge base for using NEBA in the Arctic.
2. Conduct and complete the most crucial research activities identified in phase one. It is envisioned that this work will include laboratory and modelling studies and potentially field research and will be contracted through competitive solicitation(s).
3. Organize and conduct two NEBA workshops in key arctic regions. These workshops will be used to demonstrate how the information base resulting from the review and the data from new studies are used in optimizing the NEBA process.

Progress: NewFields, Port Gamble, Washington, USA is the contractor for phase one and synthesized the existing information that supports NEBA and identified areas of research needed to better understand the consequences of various treatment strategies using an ecological consequence evaluation. This comprehensive review culminated in a phase one report with nine chapters that cover technical topic areas in detail. The JIP further tasked NewFields to adapt the format of the phase one report and literature database to support a web-based presentation of these materials as an education and resource tool for NEBA practitioners, stakeholders and the public. The technical chapters will be linked with the literature database and the supporting references. The NEBA tool is expected to be available on the JIP website in the 4Q/2014.

Phase 2: Four research projects have been initiated. ENVIRONS (formerly NewFields), Port Gamble, Washington, USA is the contractor for Project 1 and is developing ARCAT Analysis Tool for Evaluating the Ecological Consequences of Oil Spill Response. The ARCAT tables will provide rapid real time comparisons of the consequences of a selected oil spill response OSR decision(s) and they are open-ended allowing incorporation of new scientific and OSR technologies as they become available.

Akvaplan-niva, Tromsø, Norway is the contractor for Projects 2a, 2b, and 3 that will provide data and information to ENVIRONS for development of the ARCAT tables.

- Project 2A will perform field studies using in situ mesocosm to measure the exposure potential, the sensitivity and resiliency of sea ice communities. Eight mesocosms for sea ice (two control, two natural attenuation, two dispersants and two ISB) were built in France and were installed in Van Milfjord, Svea, Norway in February 2015. KOBBE crude oil from the Goliat field of the Barents Sea will be introduced into the mesocosms and treated. There will be 4 sampling times to examine the impact of the untreated and treated oil on the sea ice communities. For assessing the sensitivity and resiliency of the sea surface micro layer 12 smaller mesocosms for open water will be installed in in Van Milfjord, Svea, Norway in May 2015. The permit request to install the mesocosms and conduct the experiments was approved by Governor of Svalbard on July 8, 2014.
- Project 2B will characterize oil weathering in sea ice, sediment and rocky bottom and characterize the biodegradation processes by identifying microbial communities. There will be three control, three natural attenuation, three dispersants and three ISB experiments
- There will be 4 sampling times to examine:
    - The weathering processes
    - The biodegradation rate from the residual oil composition
    - The oil behavior and migration into the ice from the freezing period to the melting one
    - The effect of oil on the natural microbial community
- Natural rock tiles and sediment samples will be exposed to oil and situated at the same location
    - To study the fate of the oil, natural attenuation and biodegradation on solid substrate and investigate the role of sediment microorganisms and rock surface biofilms in the oil biodegradation process.
- Project 3 is a modelling study examining the impact on fish and copepod populations using population models.
    - Acute effects on populations
    - Combined acute and chronic effects on populations

Project 4 – Oil Spill Trajectory Modelling in Ice

The overall goal of this research project is to conduct research investigations in ice modelling and integrate the results into established industry oil spill trajectory models. Current ice models have intrinsic limitations, such as the inconsistent assumption of viscous-elastic rheology of the ice, that render them inaccurate. The primary research objective is to advance and expand the oil and gas industry's oil spill trajectory modelling for oil spills in ice affected waters. This project will create or adapt an existing model for predicting ice movement in the marginal and pack ice zones under applied (forecast) wind and current forcing. The new model is expected to provide increased accuracy on the behavior and movement of ice and it is intended that the model will be implementable in any of the leading oil fate and effects models, e.g., OilMap (ASA) and OSCAR (SINTEF). The model may also be applicable beyond the Arctic, for example in non-arctic but ice-prone areas (e.g., Baltic and Caspian seas). The expected outcome of this project will be an increase of the oil spill trajectory models accuracy in presence of sea ice, along with an estimation of the uncertainties in these trajectories.

Progress: The Nansen Environmental and Remote Sensing Centre (NERSC), Bergen, Norway is the contractor for this project and is developing a new sea ice model that will be tested/evaluated/validated at a regional scale as well as a new very-high resolution model to simulate sea ice dynamics in the Marginal Ice Zone (MIZ). The project is underway and progressing on schedule. The JIP organized a conference call with RPS ASA and SINTEF, potential contractors for the next project phase, to discuss project objectives, timeline, and key deliverables for information purposes and to have them familiar with the algorithms and other materials being developed by NERSC.

Project 5 - Oil Spill Detection and Mapping in Low Visibility and Ice

Remote sensing is an important element of an effective response to marine oil spills. Timely response requires rapid and sustained reconnaissance of the spill site to determine the exact location and extent of oil (particularly the thickest portion of the slick) and updated projections of oil slick's movement and fate at sea. Remote detection and mapping are essential to effectively direct spill countermeasures such as mechanical containment and recovery, dispersant application, in situ burning, and for the preparation of resources required for shoreline clean-up. Previous industry and government supported research and development has yielded technologies such as strengthened beacons designed to track the location of oiled ice, ground penetrating radar to detect oil in, on, and under ice, laser fluorosensors, and enhanced marine radar. In addition, recent tests have shown that Autonomous Underwater Vehicles (AUV's) can carry sensors capable of locating and tracking oil under ice.

The overall goal of this project is to expand industry's remote sensing and monitoring capabilities in darkness and low visibility, in pack ice, and under ice. This project is split into two elements: surface remote sensing (i.e. satellite-borne, airborne, ship-borne and on-ice detection technologies) and subsea remote sensing (i.e. mobile-ROV or AUV based and fixed detection technologies) and will be performed in a phased approach. First, an assessment and evaluation of existing and emerging technologies was performed that includes an evaluation of further research and development needs, logistical support requirements, and operational considerations including testing opportunities. Based on this assessment, a test programme was developed to identify and qualify the most promising sensors and platforms capable of determining the presence of oil on, in, and under ice and mapping its extent.

Progress: C-CORE, St. Johns, Newfoundland, Canada (surface) and Polar Ocean Service/Woods Hole Oceanographic Institute (subsea) were the contractors for the phase one technical assessment and have completed their research projects. Two reports are available on the JIP website. The first entitled:" Oil Spill Detection and Mapping in Low Visibility and Ice: Surface Remote Sensing" defined the state-of-knowledge for surface remote sensing technologies to monitor oil under varying conditions of ice and visibility (Puestow et al 2013). The second "Oil Spill Detection and Mapping in Low Visibility and Ice: Subsea Remote Sensing" defined the state-of-the-art for subsea remote sensing technologies to monitor oil under varying conditions of ice and visibility (Wilkinson, Maksym, Singh, 2013). The main findings from the reports are:

- The current state of technology in remote sensing, confirms that the industry has a range of airborne and surface imaging systems utilized from helicopters, fixed-wing aircraft, vessels and drilling platforms that have been developed and tested for the "oil on open water scenario" that can be used for ice conditions.
- There are several technologies that exist today capable of, or having the potential for, effective sensing in a broad range of ice and environmental conditions that would be experienced in the Arctic.
- Unmanned underwater vehicles (UUVs) have been successfully operating in ice-covered waters and are now a viable technology for under sea ice operations.
- UUVs, and especially autonomous underwater vehicles (AUVs), have the dual advantages of being deployable in a range of ice and weather conditions, and importantly their sensor payloads will have a direct view of oil trapped beneath the ice.
- For logistical considerations, flexibility of deployment and range, AUVs are likely the most promising underwater platform for oil spill detection.
- Detection of oil encapsulated within the ice may also be possible with some sensors mounted on UUVs, and possibly more efficiently than with surface and airborne remote sensing methods.

Phase two research experiments are being conducted to test and evaluate the performance of various surface and subsea remote sensing technologies with crude oil on, encapsulated in and under ice, in conditions that include low visibility. The experiments are using the climate controlled test basin at the U.S. Army Corps of Engineers-Cold Regions Research and Engineering Laboratory (CRREL) located in Hanover, New Hampshire, USA. The Prince William Sound - Oil Spill Recovery Institute (OSRI), Cordova, Alaska, USA is the phase two contractor. The CRREL test programme will constitute the first time that an array of above surface and subsea sensors is deployed under controlled conditions and simultaneous multi-sensor data collected from initial growth of sea ice through its melt.

Once the ice layer is formed, the team will inject various amounts of oil at specific ice thicknesses in a series of fourteen oil containment hoops. This design provides tests ranging from frazil (new) ice mixed with oil at the very beginning of the growth process, to columnar ice 80 cm thick, at the end. The oil thickness will vary from a few millimetres to 5 cm. The above and below-ice sensors will monitor the injections of oil under the various test conditions, as well as the encapsulation and eventual melt-out of the oil and ice.

The CRREL tank was cooled to initiate ice growth in October 2014. Following dry runs of the measurement sequence with the underwater carriage the first oil injection and measurement sequence completed on November 5, 2014. Further successful injections were conducted on November 10, 12, 17, 19, December 9, with the final oil injections occurring January 6-7, 2015. To capture data on the behaviour of oil of different temperatures, the injection on November 12 deliberately used slightly warm oil. Members of the technical working group had access to the CRREL Webcam that allowed them to see basic tank data or click to see pictures at the bottom (updated every 5 minutes). Data collection will continue until melt out in late February 2015.

Throughout the experiments, the test team utilized data from the sensor measurements taken under the test conditions in the basin to predict the performance of the instruments and model their performance in a wide range of field conditions. The model results are key to understanding the future potential of the different sensors under real world conditions. Specifically, the experiments aim to:

- Acquire spectral, hydro-acoustic, thermal and electromagnetic signatures of oil on, within, and underneath a solid ice sheet.
- Determine the capabilities of various sensors to detect oil in a specific ice environment created in the test tank.
- Specify design parameters for improved arctic sensors in the future.
- Recommend the most effective sensor suite for detecting oil in the ice environment, based on modelling the expected sensor performance in a wider range of real life scenarios.

Project 6 - Mechanical Recovery of Oil in Ice

The rapid containment and recovery of oil at or near the source is provided by on-site spill response vessels. Mechanical skimmers can be used to remove oil from the water surface and transfer it to a storage vessel. Floating barriers, including oil booms, are used to collect and contain spilled oil into a thicker layer. In the Arctic offshore, ice itself could act as a boom where the oil is contained in thicker layers between ice floes. Skimmers work most efficiently on thick oil layers and a variety of skimmer designs have been optimized for arctic sea conditions and several have been proven to work well. In most countries, mechanical recovery of oil is the first and preferred response, however mechanical recovery in broken ice is limited by the ability of the skimmer to encounter and remove spilled oil and to function effectively under extremely low temperatures. Another issue related to mechanical recovery is storage, transfer and disposal of the recovered oil/ice/water mixture, which is a special challenge in remote arctic areas with limited infrastructure.

The overall goal of this research project is to improve mechanical recovery of oil spills under arctic conditions. The objectives are to:

- Thoroughly examine the results obtained from previous research projects and identify a number of novel concepts, which have potential to improve efficiency of mechanical recovery under arctic conditions
- Develop a selection process by which the novel concepts can be rigorously examined
- Select and develop the most promising concepts

Progress: Utilizing results from a workshop conducted in March 2012, four novel ideas were selected to be evaluated. The JIP commissioned internal feasibility evaluations to identify the most promising technologies or equipment designs that can improve recovery of oil in ice and recommend any concepts that can be taken to the ‘proof of concept stage’. The contractor’s selected were:

- New Vessel Design – Aker Arctic
- Remote Recovery Systems – Aker Arctic
- On Board Oil/Water/Ice Separation - LAMOUR
- Onboard Oil Incineration – SL Ross Environmental Research Ltd.

The reports received were intermediate work products that would later lead to the description of the most promising solutions identified for future development. The JIP commissioned a high level summary of the four feasibility report to be released externally. The report will include information on mechanical recovery in the Arctic, acknowledge its use and limitations, and highlight the importance of in situ burning and dispersants as additional tools for arctic response. Alaska Clean Seas was selected as the contractor and will partner with the JIP to develop the summary report. The JIP is currently reviewing the draft final report.

Project 7 - In Situ Burning (ISB) of Oil in Ice-Affected Waters

Oil on water or between ice floes can be disposed of quickly, efficiently and safely by controlled burning (API 2012). This technique works most efficiently on thick oil layers as oil is contained by fire-resistant booms or ice. Through burning, an average of about 80-95% of oil volume is eliminated as gas, 1-15% as soot and 1-10% remains as a residue. Controlled burning has been proven to work well in the Arctic. The overall goal of this TWG is to ensure in situ burning (ISB) is available to industry as a response option. This requires ISB to be incorporated into contingency planning and that response organisations have the necessary resources and training. The overall goal of this research project is to prepare educational materials to raise the awareness of industry, regulators and external stakeholders of the significant body of knowledge that currently exists on all aspects of ISB. The materials are also intended to inform specialists and stakeholders interested in operational, environmental and technological details of the ISB response technique.

Progress: SL Ross Environmental Research Ltd. was the contractor for this project. This project is complete and three reports are available on the JIP website. The first report entitled: “In Situ Burning of Oil in Ice-Affected

Waters: State of Knowledge (Buist et al 2013) provides a detailed state of knowledge that summarizes the role, function, benefits and limitations of ISB as a response option in the Arctic offshore environment and covers planning and operational aspects of ISB, including the potential impacts on human health and the environment. The second " In Situ Burning of Oil in Ice-Affected Waters: Technology Summary and Lessons Learned from Key Experiments" provides a summary of relevant scientific studies and experiments as well as previous research efforts on the use of ISB in arctic environments both offshore and onshore, highlighting key findings and conclusions (Buist et al 2013). The third report "In Situ Burning in Ice-Affected Waters: Status of Regulations in Arctic and Sub-Arctic Countries" identified and summarized the regulatory requirements to obtain approval for use of ISB in Arctic nations (Buist et al 2013). The main findings from the reports are:

- Confirmation that technology exists to conduct controlled ISB of oil spilled in a wide variety of ice conditions and that ISB is one of the response techniques with the highest potential for oil spill removal in arctic conditions.
- There is a considerable body of scientific and engineering knowledge on ISB to ensure safe and effective response in open water, broken pack ice and complete ice cover, gleaned from over 40 years of research, including large-scale field experiments.
- Most of the perceived risks associated with burning oil are easily mitigated by following approved procedures, using trained personnel, and maintaining appropriate separation distances.

Project 8 - Aerial Ignition Systems for In Situ Burning

The vast majority of experience with in situ burning (ISB) is with terrestrial spills, which can be ignited by hand using simple tools (e.g., flares, drip torches, or breakable bottles of gelled gasoline). In situ burning was used with great success offshore during the 2010 Gulf of Mexico oil spill. An estimated 11,000,000 gallons of oil was safely ignited and burned during the response (Federal Interagency Solutions Group 2010). Spills to smaller water bodies, which are easy to reach, can be similarly ignited. An alternative is needed to ignite spilled oil in areas with difficult / restricted access. For the Arctic region such areas include drift and pack sea ice and open waters. Flares and gelled gasoline can be deployed by hand or mechanically from an aerial platform at low altitudes or from a nearby vessel. Safety concerns could often constrain these options. Helitorches can be suspended beneath a helicopter for more precise targeting, but there are associated aviation safety concerns and greater training needed for this option. Helitorches have often been used for ignition on land. While this technique may work well especially for the difficult-to-access spills in broken ice, helicopters have limited distance range and use for the ignition of oil spills 150 miles offshore may be problematic. Alternatively, fixed-wing aircraft have much greater range however; they do not have accurate targeting capability at their operational speeds and, consequently, are not currently considered for ISB.

The overall goal of this research project is to develop improved ignition systems to facilitate the use of ISB in offshore arctic environments, including ice when the presence of sea ice restricts use of vessels as a platform for this response option. To accomplish this effort we will involve both internal and external company aviation experts in the evaluation of ignition options by enlisting recommendations for improved ignition systems, and subsequent development, testing and certification of an improved aerial ignition system. This project is aligned with its sister project under the American Petroleum Institute ISB Program.

Progress: A seven member aviation advisory group has been established of which five are from the International Association of Oil and Gas Producers (OGP) Aviation Subcommittee and a five member ignition advisory group was also established composed of US government and industry fire experts. The project will commence in 1Q/2015.

Project 9 - Chemical Herders and In Situ Burning

Chemical herders can provide an additional tool to support oil spill response in ice and open water. ISB herding agents can be useful in thickening oil in the 30-70 percent ice concentration range so that in situ burning can be effective (SL Ross 2007). The use of chemical herders to thicken on-water slicks among drift ice for subsequent burning has been studied for a number of years (API 2012). Two field experiments using chemical herders, conducted during the SINTEF Oil in Ice JIP, were effective with greater than 90 percent removal efficiencies observed (Buist et al 2011). The overall goals of this research project are to advance the knowledge of chemical herder fate, effects, and performance to expand the operational utility of ISB in open water and in ice-affected waters.

Progress: SL Ross Environmental Research Ltd., is the contractor for this project. Experiments will be conducted at Aarhus University, Danish Center for Environment and Energy (DCE), Technical University of Denmark (DTU), and at the U.S. Army Corps of Engineers-Cold Regions Research and Engineering Laboratory (CRREL) in

Hanover, New Hampshire, USA. Four tasks are underway:

- Environmental Effects of Using Herders for In Situ Burning: This task includes laboratory burning experiments for the investigation of the environmental effects of using chemical herders for in situ burning operations, experiments to determine acute and chronic toxicity and bioaccumulation of chemical herders on arctic copepods, studying biodegradation of herders in arctic condition with water collected in the high arctic, determining the physical fate of the herder during burning, and of the smoke plume generated during test burns to determine if the herder or herder combustion products are being emitted.
- Windows-of-Opportunity for Herders: Experiments will be conducted to determine the window-of-opportunity for the two commercially-available herders (ThickSlick 6535 and OP 40) to herd slicks of different oils to ignitable thicknesses. A two-week test programme will be carried out at CRREL at a larger scale using a test protocol developed in 2009.
- Impacts of Herder Monolayer on Birds: Tasks include laboratory experiments to investigate the potential impact and effects of fouling by the herder sheen (prior to and after the burning operation) to the feathers from arctic seabirds. At DCE an ongoing study is investigating the effects on seabird feathers of fouling by burn residues and the protocol for this test is established.
- Development of Educational Materials: The project team will develop summary information and/or material (e.g., text, images, and video) to describe chemical herders, how they function, their fate and effects, and relevant research findings.

Project 10 – Field Research Field Research Using Chemical Herders to Advance In Situ Burning
ISB is an oil spill response option particularly suited to remote, ice-covered waters. Thick oil slicks are the key to effective ISB and if ice concentrations are high, the ice can limit oil spreading and keep slicks thick enough to burn. However, in drift ice conditions and open water, oil spills can rapidly spread to become too thin to ignite. Fire-resistant booms can collect and keep slicks thick in open water; however, even light ice conditions make using booms challenging.

Herders rapidly spread across a water surface to create a surfactant monolayer that reduces the water surface tension. When the surfactants reach the boundary of an oil slick, they affect the balance of surface forces acting at the edge of the slick and cause the oil to contract to a new, thicker equilibrium state. The slick thickness produced by herders, 3 to 5 mm, provides favourable conditions for effective ignition and ISB without the need for containment booms (Buist et al 2011).

Researchers have studied the use of herding agents in oil spill response since the 1970s. Extensive laboratory and field research over the past ten years has focused on the use of herders as an aid to ISB operations, primarily in open drift ice or calmer open water conditions. A series of research projects was initiated in 2004 by ExxonMobil URC and funded by many industry and government organizations to study oil-herding surfactants as an alternative to booms for thickening slicks in light ice conditions for ISB. Successful test programmes were conducted in small and large test tanks and in field settings. The work continues in 2014 under the auspices of the JIP. With aerial application of both the herding agent and ignition source (igniter), the herder/burn combination becomes an extremely rapid and effective new response tool, independent from vessel support. The slower weathering of oil slicks in ice and cold water can also extend the window of opportunity for this new tool.

The primary objective of the field research is to validate the application of chemical herders by helicopter to enhance offshore in-situ burning in ice conditions ranging from limited ice cover to ice-free waters. Specifically, the JIP will conduct up to five field releases (200 liters ~ 1 barrel) in a man-made test basin using a variety of delivery platforms to spray herders and then ignite the herded slick.

Progress: SL Ross Environmental Research Ltd., is the contractor for this project. The University of Alaska-Fairbanks (UAF) is assisting with construction of the test basin and to secure the required permits, principally air quality for burning. Based on an extensive evaluation of several site options, the JIP selected the Poker Flat Research Range, managed by UAF as the site for the temporary test basin for a herder burn project. Selection criteria included climate, distance from populated areas, land area, and logistics access. Construction of a lined, temporary gravel-berm test basin (8,700 square meters) was successfully completed September 30, 2014 before the ground froze. Experiments will be conducted in April 2015 that utilize herding agents followed by in situ burning, the aim being to apply the herder an achieve ignition solely from aerial platforms, both manned helicopters and robotic. Validating this technology will provide an important advance for marine oil spill response because it can be rapidly implemented with helicopters in contrast to existing options that depend on slow-moving vessels. The goals of the research are twofold:

- Prove the operational feasibility of an aerial herder/burn response strategy using both manned and remote-controlled helicopters.
- Reaffirm the effectiveness of herders in open water and with ice present.

Conclusion:

Oil spill response is not a competitive aspect of the oil and gas industry and the companies involved in the JIP believe that working together gives them access to a wider range of technical expertise and experience. Uniting efforts and knowledge in this JIP increases opportunities to develop and test oil spill response technologies and methodologies, conduct large scale field experiments, and raise awareness of existing industry oil spill response capabilities in the Arctic region.

The JIP has completed phase one that has included technical assessments and state of knowledge reviews in the following six areas: dispersants, environmental effects, trajectory modelling, remote sensing, mechanical recovery, and in situ burning (ISB). Nine research reports are available on the JIP website (www.arcticresponsetechnology.org) that identified and summarized the state-of-the-knowledge and regulatory status for using dispersants, remote sensing and ISB in the Arctic. These initial reports were developed by some of the world's foremost experts across industry, academia, and independent research centers, using relevant scientific studies and experiments, case studies, and previous research efforts in arctic environments both offshore and onshore.

Phase two activities are underway that include laboratory, small and medium scale tank tests, and field research. Project underway include: dispersant effectiveness testing; modelling the fate of dispersed oil in ice; assessing the environmental effects of an arctic oil spill; advancing oil spill modelling trajectory capabilities in ice; extending the capability to detect and map oil in darkness, low visibility, in and under ice; improving efficiency of mechanical recovery equipment in ice; chemical herder fate and effects; and expanding the 'window of opportunity' for ISB response operations.

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