Paper #8-1

OVERVIEW AND BACKGROUND OF OIL SPILL RESPONSE ISSUES COVERED

Prepared for the

Technology & Operations Subgroup

On March 27, 2015, the National Petroleum Council (NPC) in approving its report, *Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Technology & Operations Subgroup. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 46 such working documents used in the study analyses. Appendix D of the final NPC report provides a complete list of the 46 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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Topic Paper

(Prepared for the National Petroleum Council Study on Research to Facilitate Prudent Arctic Development)

8-1	Overview and Background of Oil Spill Response Issues Covered
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SUMMARY

The subject of oil spill response, in both open water and in the presence of ice, is a critically important issue in determining the future of drilling applications and approvals in US Arctic waters. There is a need to further develop the capabilities and understand the limitations of existing and evolving technology in the context of the Arctic environment, and in comparison with similar strategies and approaches applied with varying degrees of success in more temperate waters. This topic paper provides a background summary of historical research, and an overview of our state of knowledge regarding countermeasures and technologies already in place and being developed to respond to an accidental spill in Arctic waters.

Introduction

The subject of oil spill response, in both open water and in the presence of ice, is a critically important issue in determining the future of drilling applications and approvals in US Arctic waters. There is a need to further develop the capabilities and understand the limitations of existing and evolving technology in the context of the Arctic environment, and in comparison with similar strategies and approaches applied with varying degrees of success in more temperate waters.

Credible arctic spill scenarios for response-planning purposes can span a wide range, including: subsea batch releases (marine pipeline rupture), subsea continuous releases (e.g., subsea blowout, chronic sunken vessel or pipeline leak), surface blowouts and tanker/cargo vessel accidents. Responding to an oil spill is challenging under any circumstance. Arctic conditions introduce additional operational considerations, both positive and negative in nature, including:

- Dynamic nature and unpredictability of the ice cover.
- Difficulties of working in darkness and with periods of limited visibility during the winter months, in contrast to the extended periods of light throughout most of the year.
- Complications of continuing offshore response operations during periods of extended darkness and low visibility.
- Remoteness and great distances that are often involved in responding over vast ocean areas.

- Impacts of cold temperatures, ice and a harsh operating environment on response personnel and equipment.
- Lack of shore-based infrastructure and communications to support and sustain a response of any significant magnitude (Arctic Council - AMAP, 2009).
- Positive contributions of ice and cold water in limiting the rate and extent of spreading in many situations, buying additional time for responders and often extending the time window when different strategies are still applicable (further discussion below).
- Concerns over the sensitivity of arctic biota, exposed to oil/oil spill treating agent(s). This important topic is covered in a separate paper focusing on environmental impact issues.

This white paper provides a background summary of historical research, and an overview of our state of knowledge regarding countermeasures and technologies already in place and being developed to respond to an accidental spill in Arctic waters. The critically important aspect of oil behavior in ice is covered in Topic Paper C-1 and summarized briefly in the following points.

Key Points

The presence of sea ice and the associated cold temperatures and darkness are key features that separate arctic spill response from any other. It is worth highlighting one significant advantage that ice cover provides and that is time. Rapid response is critical to spills in open water because of the dynamic nature of marine spills – oil slicks rapidly spread to become extremely thin, break into many small slicks, and strand on shorelines. The outcome of a spill in open water is often determined within a matter of hours, allowing very little time to consider key decisions. In contrast, the presence of a significant ice cover (60% or more) can significantly slow the spreading rate and contain oil in relatively small areas, giving responders added time to develop and implement effective response strategies. This advantage at least partly offsets challenges caused by Arctic remoteness and harsh conditions.

As outlines by Dickins (2011), there are both positive and negative aspects associated with spill response operations in an arctic environment when it comes to both planning and response execution. Potential positive factors are:

- In ice-free arctic waters, increased oil viscosity at close to freezing water temperatures leads to slower spreading rates, and an increased equilibrium thickness compared to temperate areas.
- The presence of ice in the form of floes, slush and brash further constrains spreading to relatively small areas. At the same time, the reduced wave action and slower weathering in the presence of significant ice and snow cover (slower evaporation and lower emulsification rates) can extend the "windows of opportunity" and effectiveness for burning and dispersant application. (Sorstrom, et al. 2010).
- Growing ice can potentially encapsulate and isolate oil from the marine environment for many months, providing valuable additional time for planning and executing a response when conditions are more favorable.

- When ice concentrations preclude the effective use of traditional containment booms, the ice itself often serves as a natural barrier to the spread of oil. The natural containment of wind-herded oil against ice edges leads to thicker oil films that enhance the effectiveness of burning.
- The fresh condition of encapsulated oil when exposed at a later date (e.g., through ice management or natural migration/melt) enhances the chances for effective combustion and/or dispersion.
- The interaction of individual ice floes in intermediate ice concentrations can increase the available natural mixing energy and promote successful dispersion.
- The fringe of land fast ice common to most Arctic shorelines acts as an impermeable barrier and prevents oil spilled offshore at freeze-up from entering and contaminating sensitive coastal areas throughout the long winter period.
- Long periods of extended daylight during much of the summer exploration period increase the operational time for response activities.

At the same time, there a number of potential response challenges associated with responding to spills in the arctic offshore, including:

- The presence of ice, which generally limit or prevents the effective use of traditional mechanical cleanup methods in responding to large spills.
- Difficulty in finding and accessing oil trapped on or under moving ice offshore.
- Lack of oil spreading within slush and brash-filled leads and openings in the pack ice significantly decreases oil flow to the skimmer, and along with freezing of pumps, fittings and hoses, makes skimming operations extremely difficult.
- Potential gelling of crude oils with pour points at or below 0°C.
- Extended periods of winter darkness and low visibility hinder visual spill detection and monitoring, and all aspects of response operations including aviation activities associated with spotting and surveillance, dispersant application and burning.
- Lack of ports or approved disposal sites severely limit the ability to deal with large volumes of recovered oily waste.
- The general lack of infrastructure requiring that operators be entirely self-sufficient in their ability to support an extended response operation.
- Maintaining worker safety with the potential for extreme wind chill and fatigue.
- Ecological significance of biota living in close association with the ice and ice edge.

State of Knowledge

Over the past four decades, the oil and gas industry and Federal government have made significant advances in being able to detect, contain and clean up spills in Arctic environments. Many of these advances were achieved through collaborative research programs with a mix of industry and government partners (notably the Minerals Management Service (MMS), the predecessor to the current Bureau of Safety and Environmental Enforcement (BSEE)). The broad range of international oil in ice research carried out in the United States, Canada, Norway and the Baltic States since the early 1970's is summarized in Dickins and Fleet, 1992; Fingas and Hollebone, 2002; Dickins and Buist, 1999; SL Ross et al. 2010; and Potter et al., 2012). Much of the our knowledge base on oil in ice behavior and arctic spill response draws on experiences with a number of field experiments (summarized in Dickins, 2011 and discussed in an accompanying topic paper).

Over the past five years, large-scale international research efforts have focused on improving industry's capability to deal future spills in Arctic waters. Notably, the SINTEF Oil in Ice JIP advanced our knowledge in many important areas, including the use of firebooms, herding agents, in situ burning, dispersants and skimmers in ice covered waters (Sorstrom et al., 2010). Lessons learned in that program are now being applied to a broad suite of research projects initiated as part of the on going Arctic Oil Spill Response Technology Joint Industry Programme (Mullin, 2012).

Summary of Response Options

Recent key references reviewing the operational and technical aspects of arctic spill response options include: SL Ross et al. (2010), Potter et al. (2012), and NRC (2014).

Basic response strategies for spills in ice, adopted for an ice environment, include the same general suite of countermeasures used elsewhere in the world. They include:

1. Mechanical containment and recovery utilizing booms and skimmers in open water and very open pack ice, and skimmers extended from vessels directly into trapped oil pockets in heavier ice.
2. A combination of strategies to concentrate the oil and burn it *in*-situ. In an arctic environment these can involve: containment against natural ice edges without booms, fire resistant booms in open water or very open drift ice, and herding agents that can thicken and concentrate oil in open water and intermediate ice concentrations; and
3. Dispersants that disperse surface oil into the water column as small oil droplets with increased surface areas to enhance biodegradation of the oil. Application can be from the air, surface (with both natural or induced mixing energy from propeller wash) or subsea (direct injection).
4. Detection and monitoring while potentially planning a later response (e.g. burning on ice in the spring).
5. Natural attenuation through evaporation and dispersion (no deliberate response).

The following discussion provides a brief overview of our understanding of these response options. Further details are provided in individual topic papers.

<u>Detection, Delineation and Tracking</u>

In order to mount an effective response using any one of the three main countermeasures, it is critical to know not only where spilled oil is at any given time but also the distribution of film thickness. Valuable airborne and marine resources need to focus on the treatment of the thickest oil patches. This requires accurate, near real time reconnaissance presented in a map product that is immediately useable by responders in the field and decision makers in the Unified Command as the joint inter-agency/industry response management effort is often referred to.

Finding and mapping oil in open water is far from straightforward, as Leifer et al., (2012) discuss from the Deepwater Horizon experience. In the Arctic, false positives are potentially a critical issue in reliable spotting oil mixed with a range of ice types. Many sensors are negatively impacted by blowing snow, low cloud, fog, and darkness that characterize the Arctic offshore for much of the year.

Detection is generally not ambiguous in the case of a large visible spill around a vessel or around a fixed drilling platform (an exception might be a subsea pipeline leak under ice). However, continued monitoring and tracking of oiled ice as it moves away from the original discharge point presents a significant challenge with existing sensors and systems. Fortunately, the tracking aspect of this requirement is already covered by proven technology in the form of specialized GPS beacons designed to survive over long time periods in drifting ice. By deploying these beacons at closely spaced intervals from a continuous discharge site, responders can prepare to mount an in situ burning exercise along a known track when the oil surfaces through the ice in the spring.

Dickins and Andersen (2009) summarized the state of the art for remote sensing of oil in ice in these points:

- A mix of conventional airborne sensors is likely to prove effective with spills in relatively open ice cover (1-4/10) where there is a distinct oil slick covering areas of square kilometers or more – analogous to open water with some ice present.
- The use of remote sensing to detect spills contained in closely packed ice is still uncertain, requiring all weather, high resolution capabilities that have yet to be properly tested in a field situation.
- The lack of significant waves in the presence of ice complicates the use of marine or satellite radar systems, both of which depend on differences in surface waves, with and without the presence oil on the water surface, as a means of detecting the presence of oil. Surface layers of relatively freshwater when sea ice is melting can damp the capillary waves and create false positives (areas that look like possible slicks).
- The detection of oil underneath and within the ice remains a major challenge. Recent promising developments in this area include the use of ground penetrating radar from above and sonar from beneath the ice (Bradford et al., 2010; Wilkinson et al., 2012&2013). In addition efforts are on-going to explore the potential of Nuclear Magnetic Resonance (NMR) for detecting oil in ice (Nedwed et al., 2008).
- Future platforms will likely involve both unmanned aerial vehicles (UAVs) and autonomous underwater vehicles (AUVs) carrying a suite of sensors.

There is an extensive on-going research effort through the Arctic Response Technology JIP to evaluate the capabilities of a range of surface and subsea sensors to detect oil trapped in ice (summarized in Dickins, 2014).

<u>Mechanical Containment and Recovery</u>

Potter et al. (2012) define "containment and recovery or C&R" as actions taken to remove oil from the surface of water by containing the oil in a boom and/or recovering the oil with a skimming or direct suction device or sorbent material. The latter two options are unlikely to be used to any great extent offshore in the presence of ice.

Containment and Recovery (C&R) is generally regarded as the preferred response strategy for responding to marine oil spills in open water, and is mandated as the primary technique in many jurisdictions through legislative action (e.g. Alaska). Stakeholders in many countries favor containment and recovery over other oil spill countermeasures because it is viewed as directly removing oil from the marine environment. However, there are significant operational and practical limitations to solely relying on mechanical containment and recovery systems for large spills at sea in most parts of the world, and these limitations become even more critical in the Arctic.

In any large spill in open water or light ice cover, the oil usually spreads rapidly to form a very thin layer on the water surface, much less than 1 mm, before booms can be deployed. Substantial lengths (miles) of containment boom managed by large numbers of vessels are then required to concentrate these thin oil slicks for recovery. The rate at which a single skimming system encounters the slick moving at typically less than 1 knot forward speed is the key limiting factor controlling the total volume of oil that can be practically recovered as a percentage of the oil spilled. In addition, high capacity skimmers used in this application often recover significant quantities of water along with the oil. Emulsification can substantially further increase the volume of oily liquid (by several times or more), resulting in very large offshore storage demands and on-land disposal requirements with associated long-term environmental impacts. These issues are especially problematic in the US Arctic with no deep draft ports to provide marine access to shore, and few if any approved disposal sites.

The operational constraints of operating in a remote Arctic area make mounting or sustaining a massive on-water mechanical response, such as employed in the Gulf of Mexico in 2010, unworkable. Under relatively favorable sea conditions (compared with many other worldwide offshore oil producing regions) and with almost unlimited marine resources and coastal infrastructure, mechanical recovery operations in the *Deepwater Horizon* response only accounted for an estimated 2-4% of the oil volume discharged (Federal Interagency Solutions Group, 2010). One component of this disappointing performance could have been related to the lack of sufficient surveillance and spotting available to direct the mechanical teams to the thickest and most homogeneous expanses of thick oil. However, these low numbers are also a reflection of the inherent inefficiencies associated with decanting and transfer of recovered oil/emulsion to backup storage. The performance of the mechanical recovery teams looks somewhat better when calculated as a fraction of oil available on the surface, as opposed to the total volume released, but the overall recovery was still well below 10%, in keeping with many past experiences involving large widespread spills at sea.

Reliance on mechanical recovery becomes even more problematic in the presence of ice where the oil encounter rate is further reduced. Relatively small amounts of drift ice (as little as 10% coverage) can interfere greatly with the flow of oil to the skimmers and result in recovery rates far below a skimmer's theoretical capacity (Bronson et al., 2002; Potter et al., 2012; Schmidt et al., 2014). Considering the operational constraints outlined above and the basic ineffectiveness of mechanical recovery in dealing with a large spill, any future response to a large offshore arctic spill should not rely primarily upon containment and recovery (NRC 2014; Chevron Canada, 2011).

Mechanical recovery still considered a first line-of-defense and plays an important role in dealing with smaller spills contained by ice. In the Baltic Sea for example, a number of oil spills in winter shipping lanes have been successfully recovered with brush/bucket skimmers (Lampela et al., 2007; Bergstrøm, R. 2012.). In 2011, Norwegian responders recovered 50% of 112 cubic meters of heavy fuel oil spilled into freezing waters of Oslo fjord from the *Godafoss* (Bergstrøm, R. 2012).

At this stage, any future improvements in mechanical recovery systems for ice environments are expected to be evolutionary rather than revolutionary. For example, recent tests in Norway and the US focused on documenting the performance of different skimmer designs in a wide range of ice conditions and confirming the negative impact of ice interference on skimmer performance (Sorstrom et al. 2010; Schmidt et al., 2014).

<u>Dispersion</u>

Dispersants are designed to enhance natural dispersion by reducing the surface tension at the oil/water interface, making it easier for waves to create small oil droplets (generally less than 100 microns) that remain in suspension for long periods and are rapidly diluted in the water column to below toxicity thresholds of concern. Naturally available levels of nutrients can sustain effective microbial degradation, in Arctic as well as temperate waters (NRC, 2014)

There has been considerable debate over the effectiveness of dispersants on crude oil degradation at low seawater temperatures. Over the past two decades, a series of tank and basin tests and field experiments have proven that oil can be dispersed successfully in cold ice covered waters. (Brown and Goodman, 1996; Spring et al., 2006; Nedwed et al., 2007; Mullin et al., 2008; Owens et al., 2004).). Research shows that dispersants are effective on unemulsified oil at freezing temperatures as long as viscosity does not increase significantly and the oil remains a liquid well above its pour point (Venosa and Holder, 2013). New dispersant gel formulations promise increased effectiveness on cold viscous oils with longer windows of opportunity (Nedwed et al., 2007).

There is still considerable debate on the rate and extent of oil biodegradation in arctic waters. Recent studies in a laboratory at Point Barrow, Alaska demonstrated that indigenous Arctic microorganisms effectively degraded both fresh and weathered oil. Most importantly, Arctic species and their counterparts in southern waters exhibited similar tolerance to dispersed oil, and the use of dispersant was not observed to increase the toxicity of the oil (Gardiner et al, 2013

The SINTEF Oil in Ice JIP demonstrated the effectiveness of dispersants in a range of ice conditions in meso-scale basin tests and field trials. As part of that project, a new controllable applicator arm was developed to deliver dispersant more effectively to isolated oil pockets in the ice (Daling et al., 2010). Mechanical mixing can be used to overcome the lack of turbulent mixing energy in scenarios involving significant ice cover and minimal wave action, by using vessel propellers or thrusters (Nedwed et al., 2007; Daling et al., 2010). Dispersion of oil at low temperatures in the presence of ice can also be enhanced with the addition of mineral fines under turbulent mixing conditions provided by propeller wash (NRC 2014).

The *Deepwater Horizon* response demonstrated that large-scale subsea dispersant injection is potentially a very effective response measure to mitigate the effects of a subsea wellhead blowout in both temperate and Arctic waters. A major benefit of direct subsea dispersant injection is the ability to continuously respond without being impacted by darkness, extreme temperatures, strong winds, rough seas, or the presence of ice. Because of the high efficiency associated with adding dispersant directly to fresh oil at the discharge point under highly turbulent conditions, the dispersant volume can be substantially less (five times or more) than a surface application, a key advantage given the long and difficult logistics resupply chain in most Arctic areas (Brandvik et al., 2013; Johansen et al., 2013). More work needs to be done to understand the effectiveness, systems design, and short- and long-term impacts of subsea dispersant delivery (NRC, 2014).

Controlled In situ Burning (ISB)

In situ burning (ISB) in ice and arctic environments is a safe, environmentally acceptable and fully proven technique with numerous successful arctic field validations over the past 40 years. (E.g., McMinn, 1972; Norcor, 1975; Dickins and Buist, 1981; Buist and Dickins, 1987; Allen, 1990; Dickins et al., 2008). ISB is especially suited for use in the Arctic, where ice often provides a natural barrier to maintain the necessary oil thicknesses for ignition without the need for containment booms, and oil remains fresh and unemulsified for a longer period of time.

Numerous agencies, primarily in the United States, have established guidelines for the safe implementation of ISB as a countermeasure. The U.S. National Institute of Standards and Technology, NOAA, and Environment Canada have computer models used to predict safe distances for downwind smoke concentrations and eliminate any risk to responders or local populations. In 1994, the Alaska Regional Response Team incorporated ISB guidelines for Alaska into its Unified Response Plan, becoming the first Arctic area to formally consider ISB as an oil spill countermeasure (ARRT, 2008). Their guidelines are considered the most fully-developed to date, and contain safe distances for responders and the public under different conditions (ADEC et al. 2001 (Rev. April 2007).

Experience with burning fresh, weathered, and emulsified oils and petroleum products in a range of ice conditions has led to some basic “rules of thumb”. The most important parameter is the oil thickness. In order to achieve 60-80% removal efficiency in most situations, the starting thickness of crude oil needs to be on the order of 3-5 mm. (Buist et al., 2003). While this thickness, may not always occur naturally, the required thickness for successful ignition and burning may occur through wind herding against ice edges, use of fireproof booms and the use of herding agents.

In arctic field tests, burn removal rates have ranged from 65 to well over 90%, depending mainly on the size distribution of the melt pools on ice. In an experimental spill under solid ice in Norway, 3,400 liters of crude oil were allowed to surface naturally through the ice and then burned with an overall removal efficiency of 96%. A portion of this oil was exposed to weathering on the ice surface for over one month before being successfully ignited (Brandvik et al., 2006).

Despite highly successful test results over four decades, there is continued concern among some non-governmental organizations drawing conclusions without the insight of actual research, that actual spill conditions could reduce the effectiveness of ISB to far below these theoretical maximums (e.g., WWF, 2010; Goodyear and Beach, 2012). In practice, experiences with very large burns at sea have demonstrated that efficiencies increase with scale, as the oil is pulled into the burn area by thermally-induced, strong radial air inflow at the surface (Buist et al., 1994; Mabile 2012).

Similar high efficiencies were documented for ISB of oil mixed with ice within fire-resistant booms during the 2009 SINTEF Oil in Ice Field Experiments (Potter et al., 2012). In the same project, oil that was allowed to drift and weather in very close pack ice for over a week was also successfully ignited and burned (Brandvik et al., 2010).

ISB was used successfully on a trial basis during the *Exxon Valdez* response (Allen, 1990). In 1993, a U.S.-Canada experiment off Newfoundland successfully burned crude oil in fire-resistant booms in the open ocean and monitored a large suite of environmental parameters, including smoke composition (carcinogens, PAH etc.), residue toxicity, and upper water column impacts (Fingas et al., 1995). Results demonstrated that when conducted in accord with established guidelines, ISB is safe and poses no unacceptable risk to human populations, wildlife or responders.

Most recently, the massive ISB operation in response to the *Deepwater Horizon* blowout provided a unique set of full-scale operational data applicable to response planning for Arctic offshore areas in the summer. Approximately 400 controlled burns removed an estimated 220,000 to 310,000 barrels of oil from the Gulf of Mexico. Other than a single burn conducted with fire boom during the Exxon Valdez spill, this was the first large-scale application of controlled burning in an operational setting (Allen et al., 2011).

With aerial ignition systems such as the Helitorch, multiple oiled pools on the ice in the spring can be ignited quickly over a wide area. Future research is aimed at developing more efficient, high-speed aerial ignitor systems with larger payloads that could reach spills further offshore (ART – JIP).

The concept of using herding agents to burn free-drifting oil slicks in open water or very open pack ice was successfully field tested for the first time in the Norwegian Barents Sea in 2008 as part of a JIP on Oil Spill Contingency for Arctic and Ice-Covered Waters (Buist et al., 2010). Burn removal effectiveness in that test was estimated to be in the order of 90%. The residue floated readily and was recovered manually from the water surface and ice edges. Buist et al. (2011) summarizes past research into chemical herders and concludes that oil spill responders should consider utilizing them to enhance ISB in light to medium ice concentrations.

A new ISB project planned under the Arctic Response Technology JIP includes the validation and testing aerial application systems for chemical herders using both manned and remote-controlled helicopters. The JIP is also initiating a new project (2014/15) to evaluate the potential of chemical herders under different oil properties and weathering, as well as investigating windows of opportunity for their use. The JIP recently published a comprehensive state of knowledge review of in situ burning in the Arctic, including all known references. (Buist et al., 2013).

Synopsis
There is an extensive background of knowledge regarding oil spill behavior in Arctic conditions as well as the effectiveness and applicability of different response strategies in ice and cold water.

While technology enhancements will continue to improve the operability and effectiveness of different response systems in ice, there is an on going challenge associated with informing and educating a diverse set of stakeholder groups, residents and regulators. The overall goal is to gain acceptance that all response options, including burning and dispersants need to be available for responders to use on short notice as the spill behavior and environmental conditions dictate. Any such decisions to employ a particular strategy need to be contingent on demonstrating a positive net environmental benefit.

Expectation management is needed in order to better understand oil spill response technology, real-world operational constraints, and what levels of success can be achieved under various environmental conditions. With the best of intentions, regulations have been created to ensure that adequate equipment and personnel are available to handle a so-called "Worst Case Discharge" of oil from vessels, exploration and production platforms, pipelines, and many other petroleum-handling facilities. Regulations and oil spill contingency plans often describe the resources and tactics needed for oil spill control as "Planning" standards, not "Performance" standards. However, even when a good planning standard is developed, based on meaningful system performance criteria), that standard can still be misunderstood and misused (Genwest and Spiltec, 2012). The misuse occurs when planners and regulators use the standard to determine the amount of resources (i.e., vessels, skimmers, booms, aircraft, people, etc.) needed to clean up a "Worst Case Discharge".

There needs to be an educated and more balanced perspective regarding the full range of available response techniques, including controlled burning and the application of chemical dispersants. The response community and the general public must be informed of the benefits, limitations and tradeoffs associated with these techniques, and be provided the information to understand that even under the best of conditions, one can never expect to recover or eliminate all of the oil spilled. Federal and state planning standards and regulations need to be developed that address realistic operational and environmental constraints, as well as practical levels of response capability. The type and number of resources that can be maintained and operated safely and effectively for a given area, project, or facility should reflect a careful assessment of the most probable spill events that might occur, while recognizing that backup resources can be cascaded in within a short period of time to support a more serious spill event (Allen, pers. comm., 2014)

A significant remaining technical constraint concerns our ability to detect and map oil on, in or under ice at a tactical scale in darkness and low visibility over a range of scenarios, and ice conditions.

References

Alaska Clean Seas. 2013. *Alaska Clean Seas Technical Manual* (2 volumes), Revision 11, Prudhoe Bay, Alaska, USA, 99734-0022.

Alaska Regional Response Team, 2008. In-Situ Burning Guidelines for Alaska: Revision 1. Appendix II, Annex F, in The Alaska Federal/State Preparedness Plan for Response to Oil and Hazardous Substance Discharges/Releases.

Allen, A.A. 1990. Contained Controlled Burning of Spilled Oil During the Exxon Valdez Oil Spill. Proceedings of the Arctic and Marine Oilspill Program Technical Seminar No. 13, *Environment Canada*, Ottawa. pp. 305-313.

Allen A.A., D. Jager, N.J. Mabile, and D. Costanzo. 2011. The Use of Controlled Burning during the Gulf of Mexico Deepwater Horizon MC-252 Oil Spill Response. International Oil Spill Conference Proceedings: March 2011, Vol. 2011, No. 1, pp. abs194.

Arctic Council. 2009. Arctic Marine Shipping Assessment.

Bergstrøm, R. 2012. Lessons learned - the Godafoss accident in Feb. 2011: Oil spill recovery at -20°C. Proceedings Interspill Conference, London.

Brandvik, P.-J., O. Johansen and U. Farooq. 2013. Droplet breakup in subsea oil releases – Part 1: Experimental study of droplet breakup and effectiveness of dispersant injection. *Marine Pollution Bulletin* 73(1): 319-326.

Bradford, J. H., D.F. Dickins, D.F., and P.J. Brandvik. 2010. Assessing the Potential to Detect Oil Spills In and Under Snow Using Airborne Ground-Penetrating Radar. *Geophysics, 75*(2).

Brandvik, P.J., L-G., Faskness, D.F. Dickins, J. Bradford. 2006. Weathering of Oil Spills Under Arctic Conditions: Field Experiments with Different Ice Conditions Followed by In-situ Burning. Presented at the 2006 Third Annual NATO/CCMS Oil Spill Response Workshop, Oct 11-13, Dartmouth, NS, Canada.

Bronson, M., Thompson, E, McAdams F. and J. McHale. 2002. Ice Effects on Barge-based Oil Spill Response Systems in the Alaskan Beaufort Sea. Proceedings 25th Arctic and Marine Oilspill Program Technical Seminar (AMOP), Calgary, pp 1253-1268.

Buist, I.A., S.G. Potter, B.K. Trudel, S.R. Shelnutt, A.H. Walker, D.K. Scholz, P.J. Brandvik, J. Fritt-Rasmussen, A.A. Allen, and P. Smith. 24 October 2013. In Situ Burning in Ice-Affected Waters: State of Knowledge Report- Final Report 7.1.1 to the Arctic Response Technology Joint Industry Programme.

Buist I.A., S. Potter, T. Nedwed and J. Mullin. 2011. Herding surfactants to contract and thicken oil spills in pack ice for in situ burning. S.L. Ross Environmental Research, ExxonMobil and US Department of the Interior (BOEM), In *Cold Regions Science and Technology* 67 (2011) 3–23.

Buist, I., Potter, S., Sørstrøm, S.E. 2010. Barents Sea Field Test of Herder to Thicken Oil for *In Situ* Burning in Drift Ice. Proceedings 33rd AMOP Technical Seminar, Halifax NS.

Buist, I., Dickins, D., Majors, L., Linderman, K., Mullin, J., Owens, C. 2003. Tests to Determine the Limits to in-situ Burning in Brash and Frazil Ice. Proceedings Arctic and Marine Oilspill Program Technical Seminar No. 26, Vol. 2, pp 629-648. Environment Canada, Ottawa.

Buist, I.A., S.L. Ross, B.K. Trudel, E. Taylor, T.G. Campbell, P.A. Westphal, M.R. Myers, G.S. Ronzio, A.A. Allen and A.B. Nordvik. 1994. The Science, Technology and Effects of Controlled Burning of Oil Spills at Sea. MSRC Technical Report Series 94-013, Marine Spill Response Corporation, Washington, DC, pp. 382.

Buist, I., Dickins, D. 1987. Experimental Spills of Crude Oil in Pack Ice. Proceedings 1987 International Oil Spill Conference. American Petroleum Institute. Washington, pp 373-381.

Chevron Canada Limited. 2011. Arctic Offshore Drilling Review Submission Part 2: Responses to NEB Calls for Information 1 and 2. National Energy Board - Public Review of Arctic Safety and Environmental Offshore Drilling Requirements. NEB File No. OF-EP-Gen-AODR 01.

Daling, P., P.J. Brandvik, F. Leirvik, A. Holumsnes, and C. Rasmussen. 2010. Development and field testing of a flexible system for application of dispersants to oil spills in ice. Proceedings 33rd Arctic and Marine Oilspill Program Technical Seminar, Halifax NS, pp 787-814.

Dickins, D.F. 2014. Oil Spills in Ice: Remote Sensing – Technology Overview and Upcoming JIP Research. Presentation at the International Oil Spill Conference, Savannah, GA.

Dickins, D.F. Behavior of Oil Spills in Ice and Implications for Arctic Spill Response. Paper No. OTC22126, Proceedings Arctic Technology Conference, Feb 7-9, 2011, Houston.

Dickins, D.F. and J.H.S. Andersen. 2009. Remote Sensing Technology Review and Screening. SINTEF Oil in Ice JIP, Report 22.

Dickins, D., Brandvik, P.J., Bradford, J., Faksness, L.-G., Liberty, L., Daniloff, R. 2008a. Svalbard 2006 Experimental Oil Spill Under Ice: Remote Sensing, Oil Weathering Under Arctic Conditions and Assessment of Oil Removal by In-situ Burning. Proceedings 2008 International Oil Spill Conference, Savannah, Georgia.

Dickins, D., Buist, I. 1999.Oil Spill Countermeasures for Ice Covered Waters. *Journal of Pure and Applied Chemistry*, Vol. 71, No 1, London, 1999.

Dickins, D.F., Buist, I.A. 1981. Oil and Gas Under Sea Ice Study: Vols. I&2. Prepared by Dome Petroleum Ltd. for COOSRA, Report CV-1, Calgary, AB, Canada (also published in Proceedings 1981 International Oil Spill Conference, Atlanta GA).

DF Dickins Associates Ltd., and Fleet Technology Limited. 1992. Behaviour of spilled oil at sea (BOSS): Oil-in-ice fate and behavior. Draft report submitted to Environment Canada, U.S. Minerals Management Service and American Petroleum Institute.

Federal Interagency Solutions Group. Nov 2010. Oil Budget Calculator – Deepwater Horizon. Report to the National Incident Command.

Fingas, M.F., Hollebone, B. P. 2002. Behaviour of Oil in Freezing Environments: A Literature Review. Proceedings Arctic and Marine Oilspill Program Technical Seminar No. 25, Vol. 2, pp 1191-1205. Environment Canada, Ottawa.

Fingas, M.F., G. Halley, F. Ackerman, R. Nelson, M.C. Bissonnette, N. Laroche, Z. Wang, P. Lambert, K. Li, P. Jokuty, G. Sergy, W. Halley, J. Latour, R. Galarneau, B. Ryan, P.R. Campagna, R.D. Turpin, E.J. Tennyson, J. Mullin, L. Hannon, D. Aurand and R. Hiltabrand, 1995. The Newfoundland offshore burn experiment. Proceedings 1995 International Oil Spill Conference, pp 123-132. American Petroleum Institute. Washington, DC.

Gardiner, W.W., et al. (2013) "The Acute Toxicity of Chemically and Physically Dispersed Crude Oil to Key Arctic Species Under Arctic Conditions During the Open Water Season." *Environmental Toxicology and Chemistry,* 32(10), 2284-2300.

Genwest and Spiltec. 2012. Effective Daily Recovery Capacity (EDRC) Project Final Report. Prepared for Bureau of Safety and Environmental Enforcement, Herndon VA.

Goodyear, J., and B. Beach. 2012. Environmental Risks with Proposed Offshore Oil and Gas Development off Alaska's North Slope, IP: 12-08-A. National Resources Defense Council.

Johansen, O., P.-J. Brandvik, and U. Farooq. 2013. Droplet breakup in subsea oil releases – Part 2: Predictions of droplet size distributions with and without injection of chemical dispersants. *Marine Pollution Bulletin* 73(1): 327-335.

Lampela, K. 2007. Baltic approach to oil spill recovery in ice: case studies and recent development in Baltic Sea States. In: Proceedings International Oil & Ice Workshop 2007. Minerals Management Service. Herndon, VA.

Leifer, I., W.J. Lehr, D. Simecek-Beatty, E. Bradley, R. Clark, P. Dennison, H. Yongxiang, S. Matheson, C.E. Jones, B. Holg, M. Reif, D. A. Roberts, J. Sveikovsky, G. Swayze, and JI. Wozencraft. 2012. State of the art satellite and airborne marine oil spill remote sensing: Application to the BP Deepwater Horizon oil spill. Elsevier. *Remote Sensing of Environment* 124: 185-209.

Mabile, N. 2012. The Coming of Age of Controlled In-Situ Burning: Transition from Alternative Technology to a Conventional Offshore Spill Response Option. Presentation at Interspill 2012, London, UK.

McMinn, T.J. 1972. Crude Oil Behavior on Arctic Winter Ice: Final Report. Office of Research and Development, United States Coast Guard, Project 734108, Wash. D.C., NTIS Publication No. AP-754, 261 p. (also published as McMinn, LTJG T.J. 1973. Oil Spill Behavior in a Winter Arctic Environment. Offshore Technology Conference, Houston)

Mullin, J. 2012. The Oil and Gas Industry's Commitment to Responsible Arctic Operations: An Innovative Arctic Oil Spill Response Technology - Joint Industry Program. OTC Paper 23800, In Proceedings Offshore Technology Conference, Houston, TX.

Mullin, J., R. Belore and K. Trudel. 2008. Cold water dispersant effectiveness experiments conducted at OHMSETT with Alaskan crude oils using Corexit 9500 and 9527 dispersants. In: Proceedings of the 2008 International Oil Spill Conference, 4-8 May, 2008, Savannah, Georgia. American Petroleum Institute, Washington DC. pp. 817-822.

National Research Council. 2014. Responding to Oil Spills in the Arctic. Washington, DC.

Nedwed, T., G.P. Canevari, R. Belore, J. Clark, T. Coolbaugh and A. Tidwell. 2011. New dispersant gel effective on cold, viscous oils. Poster: The 2011 International Oil Spill Conference, Portland, Oregon. American Petroleum Institute, Washington DC.

Nedwed, T., W. Spring, R. Belore and D. Blanchet. 2007. Basin- scale testing of ASD icebreaker enhanced chemical dispersion of oil spills. Proceedings Arctic and Marine Oilspill Program (AMOP) Technical Seminar. No. 30, Vol. 1, pp. 151-160. Environment Canada, Ottawa, Canada.

Owens, E.H., and D.F. Dickins. 2014. Guide to Oil Spill Response in Snow and Ice Conditions. In preparation by Owens Coastal Consultants and DF Dickins Associates for the Arctic Council EPPR Working Group and International Maritime Organization, London.

Owens, E.H., L. Solsberg, M. West, and M. McGrath. 1998. Field Guide for Oil Spill Response in Arctic Waters. Prepared for the Arctic Council, EPPR Working Group, Published by Environment Canada, Yellowknife.

Potter, S. and I. Buist. 2010. In-situ Burning in Arctic and Ice-covered Waters: Tests of fire-resistant booms in low concentrations of drift ice. Proceedings 33rd Arctic and Marine Oilspill Program Technical Seminar, Halifax NS, pp 743-754.

Norcor. 1975. The Interaction of Crude Oil with Arctic Sea Ice. Beaufort Sea Project Technical Report No. 27, Canadian Department of Environment, Victoria, BC, Canada.

Potter, S., I. Buist, K. Trudel, D. Dickins and E. Owens. February 2012. Spill Response in the Arctic Offshore. Prepared for the American Petroleum Institute and the Joint Industry Programme on Oil Spill Recovery in Ice, D. Scholz (ed.). American Petroleum Institute, Washington. pp. 157.

S.L. Ross Environmental Research Ltd., DF Dickins Associates Ltd., and Envision Planning Solutions Inc. 2010. Beaufort Sea Oil Spills State of Knowledge Review and Identification of Key Issues. Environmental Studies Research Funds Report No. 177. Calgary. pp. 126.

Schmidt, B., P. Meyer and S. Potter. 2014. Testing of Oil Recovery Skimmers in Ice at Ohmsett. Proceedings The 37th *AMOP* Technical Seminar on Environmental Contamination and Response, Canmore, AB.

Sørstrøm, S.E., P.-J. Brandvik, P.J., Buist, I., Daling, P., Dickins, D., Faksness, L.-G., Potter, S., Rasmussen, J.F., Singsaas, I.. 2010. Joint Industry Program on Oil Spill Contingency for Arctic and Ice-covered Waters: Summary Report. Oil in Ice JIP Report No. 32, SINTEF, Trondheim, Norway.

Venosa, A.D. and E.L. Holder. 2013. Determining the dispersibility of South Louisiana crude oil by eight oil dispersant products listed on the NCP Product Schedule. *Marine Pollution Bulletin* 66: 73-77.

Wilkinson, J., H. Singh and T. Maksym 2012. Information sheet reporting preliminary results from study on locating oil under ice with sonar and cameras. Joint research program between the Scottish Marine Institute, Woods Hole Oceanographic Institute, CRREL and the Prince William Sound Oil Spill Research Institute.

Wilkinson, J., T. Maksym and H. Singh. October 2013. Capabilities for Detection of Oil Spills Under Sea Ice from Autonomous Underwater Vehicles. Report by Polar Ocean Services and the Woods Hole Oceanographic Institution for the Arctic Response Technology Joint Industry Programme.

WWF (World Wildlife Fund). 2010. *Drilling for Oil in the Arctic: Too Soon, Too Risky.*