Paper #8-8

TOXICITY OF OIL TO ARCTIC ORGANISMS AND NATURAL OIL BIODEGRADATION

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)		
8-8	**Toxicity of Oil to Arctic Organisms and Natural Oil Biodegradation**	
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SUMMARY This topic paper reviews the toxicity and biodegradation of treated and untreated oil on Arctic ecosystems. It also describes the Net Environmental Benefit Analysis approach that is used for the selection of response techniques that would minimize environmental damage.		

RECOMMENDATION: DOE should be aware that the substantial amount of scientific data is available to access potential impacts of oil, dispersed oil and products of in-situ burning on arctic marine organisms. This information indicates that sensitivity of arctic species is not significantly different from the sensitivity of temperate species, dispersants don't increase toxicity of the oil, dispersed oil biodegrades even in the cold Arctic waters, and environmental impacts of controlled burning are very minimal.

RECOMMENDATION: Selection of the response options should be driven by the Net Environmental Benefit Analysis (NEBA) incorporating latest scientific data and embracing ecosystem-based approach. Available data already allow conducting Arctic NEBA and selecting response options that will result in the maximum environmental protection. To further refine this approach, additional studies can be conducted to better understand population and community dynamics as well as resilience of various arctic ecosystems.

Oil behaviour in arctic environment and its impact on the arctic ecosystem are described in topic papers 9.3. This section reviews the changes in environmental impacts resulting from the application of response strategies, toxicity and biodegradation of treated and untreated oil, and Net Environmental Benefit Analysis that is used for the selection of response techniques that would minimize environmental damage.

<u>Net Environmental Benefit Analysis</u>

The use of mechanical recovery, dispersants and in-situ burning alters fate and behaviour of an oil slick and its potential to impact arctic ecosystem. This change is analysed through a Net Environmental Benefit Analysis (NEBA), which is a process used by spill response decision-makers in determining a response technique or a set of response techniques that will minimize environmental impact caused by oil and facilitate the most rapid ecosystem recovery. Efroymson et al., (2003) describes NEBA as a methodology for comparing and ranking the net environmental benefit associated with multiple response alternatives. It evaluates the gains in environmental services or other ecological properties attained by remediation, minus the environmental injuries caused by those actions. At its core, NEBA is an assessment of the advantages and disadvantages of implementing differing response options judged against a natural attenuation strategy. NEBA is not a new invention – it has been used in practice for many years following lessons learnt from spills in the 1980s (Shigenaka, 2014).

Mechanical recovery may be effective when recovering small oil spills contained between ice floes, but it will have limited efficiency on large spread out slicks. Efficiency is further degraded by the presence of any significant ice cover or high waves. NEBA evaluates the volume of oil that can be treated by a response technique under specific spill conditions balances this benefit against the potential environmental impacts of treated as well of remaining oil. It will also consider overall impacts of the response actions themselves. For example, a large number of ice capable vessels conducting mechanical recovery could create airborne and underwater noise, air pollution and waste disposal issues that exceed the benefits of the any oil removal that they can provide.

Chemical dispersion introduces oil into the water column while reducing the presence of the oil at the sea surface. Organisms utilizing the sea surface hence will be less exposed to the chemical and physical impacts of dispersed oil. Although organisms living within the pelagic water column become exposed to oil, these exposures are limited spatially and temporally because dispersed oil plumes rapidly dilute in the open sea. In addition, because chemically dispersed oil droplets are in the <100 micron range, a larger surface area is available for bacterial colonization and natural biodegradation. When chemical dispersants are not used, a portion of the petroleum will likely remain as a potentially persistent surface slick that can weather to form a stable emulsion of oil and be transported over large distances.

In-situ burning converts the majority of a surface oil slick into airborne gases, water vapour and soot, leaving a much smaller volume of residue composed of less toxic hydrocarbons. NEBA evaluates both potential impacts of the airborne plume as well as impact of the residue relative to the impacts of untreated oil remaining on the sea surface.

Scientific data and lessons learned from historical spills are available to support NEBA and response techniques selection for arctic environment. In this analysis, environmental impact severity, its duration and recovery of populations, communities, and ecosystems should all be considered. Several studies have addressed community level impacts in the Arctic (Chapman and Riddle, 2003 and 2005; Olsen et al., 2007). Our understanding of potential environmental impacts can be further advanced by additional studies of the population and community dynamics as well as evaluation of how resilient arctic communities are and how they recover after initial impact.

Exposure of marine organisms to dispersed oil

The key determinants of effects on biota exposed to dispersed oil are the sensitivity of the species and the level and duration of the exposure. Numerous studies have contributed to our understanding of the fate and behaviour of physically and chemically dispersed oil and this information can be used to assess exposure to water column biota during a spill event. (Cormack and Nichols, 1977; McAuliffe et al., 1980 and 1981; Lichtentaler and Daling, 1983; Lunel, 1994; Lewis et al., 1995; Brandvik et al., 1996; Strom-Kristiansen et al., 1997). These studies have shown that under open water conditions, both physically and chemically dispersed oils dilute rapidly as a result of wave and current action and water mixing. This results in oil concentrations quickly reducing over time. Available data suggest that, following initial dispersion, maximum dispersed oil concentrations are less than 50 mg/L and that dispersed oil concentrations dilute to 1 to 2 mg/L in less than 2 hours (Cormack and Nichols, 1977; McAuliffe et al., 1980 and 1981; Lunel, 1994; Strom-Kristiansen et al., 1997; Daling and Indrebo, 1996). Trudel et al. (2009) showed that, even in closed wave tanks, concentrations of dispersed oil are rarely higher than 100 mg/L. With time dispersed oil plumes continue to dilute and offshore concentrations of dispersed oil are estimated to become very low in less than a day (Cormack and Nichols, 1977; McAuliffe et al., 1980; IPIECA, 2001; French McCay and Payne, 2001; French McCay et al., 2006). As a result, exposure of water column biota to offshore dispersed oil (chemically or physically) is short and for surface application of dispersants limited to the few top meters of the water column directly underneath the slick (Potter et al., 2012).

Small-scale field tests have indicated that dispersants also rapidly dilute even in the absence of dispersed oil. Concentrations of dispersant in water have been shown to reduce to less than 1 mg/L within hours, which are generally below estimated toxicity levels derived from experiments with constant exposure (NRC, 1989).

Dispersed oil toxicity

Many years of laboratory testing and field research have generated a vast amount of toxicity data that can be used for assessing environmental impacts. Several field and mesocosm studies have not only characterized the environmental fate of the oil, but also characterized impacts on biota (Gilfillan et al., 1983; NRC, 1989; Brandvik et al., 1996; Lewis and Aurand, 1997; Bragin et al., 1999; Coelho et al., 2002; Baca et al., 2005). Not all these studies provide sufficiently detailed exposure–response data. Most of the currently available toxicity data on chemically dispersed oils were generated under controlled laboratory test conditions. The challenge with much of the available data is that many tests result in exposure conditions far in excess of what would be experienced under field conditions with more realistic dilution rates. Therefore, additional interpretation or modelling is required before these data can be used in NEBA based decision making (NRC, 1989 and 2005; Henry, 2005; Lubchenco et al., 2012). Bajerano et al. (2014) discussed the large variety in exposure methods, oil type and treatments and the complications when interpreting and applying these data for impact assessments. Several efforts have been made in reviewing the available laboratory toxicity data to facilitate the development of useful benchmarks that help inform decision makers (NRC, 1989, 2003 and 2005, Markarian et al., 1995; Di Toro et al., 2000 and 2007; French-McCay, 2002; Olsen et al., 2013; Bajerano et al., 2014).

Results from laboratory exposure tests show indicate that for most species, acute toxicity levels (48-96h) for dispersed oil are in the order of 1 mg/L. Water column concentrations exceeding these levels in an actual surface application of dispersants in the field may only occur in the top few meters for a limited time because of rapid dilution. This finding is confirmed through monitoring of accidental spills; significant effects on fish populations from dispersant use are generally not observed. Monitoring efforts conducted after the Deep Water Horizon incident indicated no significant losses of juvenile fish and larvae; catch rates remained relatively high after the spill compared to the previous four years (Fodrie and Heck, 2011).

Sensitivity of arctic vs. non-arctic species

There has been a considerable effort in the past five to ten years to better understand the sensitivity of arctic species to dispersed oil. The majority of studies were conducted with crude oil or single polycyclic aromatic compounds exposing mainly copepods and fish larvae. (e.g. Christiansen et al., 1996; Ingebritsen et al., 2000; Perkins et al., 2005; Jensen et al., 2008; Baussant et al., 2009; Skadsheim et al., 2009; Jensen and Carroll, 2010; Hansen et al., 2011; Hjorth and Nielsen, 2011; Grenvald et al., 2013). Several studies addressed the toxicity of chemically and physically dispersed oil (e.g. Hansen et al. 2012; Gardiner et al. 2013; McFarlin et al., 2011). These studies showed that, for field relevant concentrations, the same concentration of chemically dispersed oil is no more toxic than physically dispersed oil and that the dispersants' acute toxicity only occurs at much higher water column concentrations than expected with any proposed use of the dispersant product.

The amount of data specific to the toxicity of dispersed oil to arctic species is limited compared to the data available on sub-arctic, temperate, and tropical species. Although regionally specific toxicity data are sometimes desired, there are several practical challenges with testing arctic species in standard laboratory tests. A number of studies have, therefore, assessed the potential relevance of non-arctic toxicity data for assessing arctic species' sensitivity (De Hoop et al., 2011; Olsen et al., 2011; Word and Gardiner, in prep). There is a body of evidence that indicates that, based on acute effects, arctic species are no more sensitive than temperate species to petroleum related compounds. Several studies indicated that arctic species require a longer period of time to exhibit effects associated with petroleum exposures (Chapman and Riddle, 2005; Olsen et al., 2011, Gardiner et al. 2013; Hansen et al. 2013). Many factors can explain the increased response time of arctic species as they have a number of morphological and physiological adaptations to survive at cold temperatures (e.g. lipid stores, decreased metabolic rates for some larger body size compared to temperate counterparts, and slower digestion) that may affect toxic responses (De Hoop et al., 2011). Olsen et al., (2011) and De Hoop et al., (2011) concluded that toxicity data for temperate regions are transferrable to the Arctic for the chemical 2-methyl naphthalene, naphthalene, and physically and chemically dispersed oil, as long as extrapolation techniques are properly applied and uncertainties are taken into consideration. These findings are supported by Word and Gardiner (in preparation) who compare the relative sensitivity of arctic and non-arctic species using measured and literature data. A report from the Norwegian Research Council that reviews 10 years of research on long-term environmental effects of the oil and gas industry (NFR, 2012) concludes that arctic organisms themselves are not necessarily more sensitive to oil discharges than temperate organisms.

Impacts from In-situ Burning

Toxicity data for dispersed oil are typically needed to evaluate the use of chemical dispersants compared to physical dispersion and natural attenuation. For in-situ burning, however, the concern is related to the potential impacts of the smoke plume and toxicity of the unburnt residue. Studies of the emission levels from experimental burns have shown that about 85 to 95% of the burned oil becomes carbon dioxide and water, 5 to 15% of the oil is not burned efficiently and is converted to particulates, mostly soot, and the rest, 1-3%, is comprised of other combustion by-products (e.g. nitrogen dioxide, sulphur dioxide, carbon monoxide and poly aromatic hydrocarbons). The burn residue from a typical in-situ burn of crude oil is a semisolid, tar-like layer (Potter et al., 2012).

Two programmes studied the potential environmental effects of in-situ burning in the 90s. These programs looked at various aspects of smoke emissions and soot production. (Fingas et al., 1994; McGrattan et al., 1994 and 1995). Studies that also examined the burn residue showed the low toxicity of the burn residue to salt water, freshwater and benthic species (Daykin et al., 1994; Blenkinsopp et al., 1997). In two known cases; the *Haven* spill in Italy in 1991 and the *Honam Jade* spill in South Korea in 1983, sunken burn residues affected benthos in only a relatively small localized area and interrupted fishing activities (Martinelli et al., 1995; Moller, 1992).

The smoke produced during in-situ burning and the concentrations of particles within this plume that are small enough to be inhaled into the lungs are usually of most concern to the public. In addition smoke plumes are also of concern because they obstruct visibility and may pose a safety hazard to ships and aircrafts. The smoke plume may also result in limited aesthetic impacts. By establishing exclusion zones these adverse effects of in-situ burn activities are easily managed. It is unlikely that these potential impacts will prevent in-situ burn operations in the Arctic due to the relatively low population densities in these areas (Potter et al., 2012).

Biodegradation

Creation of a large number of small oil droplets leads to increased surface area available for degradation by bacteria naturally present in marine environment, which colonize dispersed oil droplets within a few days (Lessard and Demarco, 2000; MacNaughton et al., 2003). As a result of rapid dilution offshore, natural levels of biologically available oxygen and nutrients are not depleted and are sufficient to support efficient oil biodegradation (Swannell and Daniel, 1999; Hazen et al., 2010; Prince and Butler, 2013). Bacteria capable of degrading hydrocarbons were found in all marine environments including Arctic (Zinger et al., 2011; Ghioglione et al., 2012; Sul et al., 2013; Deppe et al., 2005; Hazen et al., 2010).

In order to investigate the rate of oil biodegradation under colder climate conditions, Venosa and Holder (2007) studied the biodegradation of dispersed Alaska North Slope crude oil at 5ºC and 20ºC. They found rapid and only slightly reduced biodegradation rates at 5ºC compare to the 20ºC. McFarlin (2011) also demonstrated that biodegradation of fresh and weathered Alaska North Slope crude oil with indigenous arctic microorganisms took place at both 2°C and -1°C. Addition of Corexit 9500 enhanced the oil degradation process. These results support the findings by Brakstad and Bonaunet (2006) that crude oil is degradable by indigenous microorganism populations in the arctic marine environment, even at near-freezing temperatures, although at slower rates compared to higher temperatures (Margesin et al. 2003; Michaud et al. 2004). These studies as well as studies conducted by Hazen et al. (2010) and Brakstad (2014) provide evidence that biodegradation of dispersed oil readily occurs at temperatures similar to those in arctic waters.

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