CALIFORNIA
DEPARTMENT OF FISH AND WILDLIFE
OFFICE OF SPILL PREVENTION AND RESPONSE

REPORT ON
BEST ACHIEVABLE TECHNOLOGY
Applied Response Technologies (ART)

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EXECUTIVE SUMMARY

There have been considerable advances in the last two decades in the fields of oil spill response research and oil spill response planning that address the use of Applied Response Technology (ART).

There are two basic categories of ARTs: the use of oil spill cleanup agents (OSCA) and the use of *in-situ* burning of oil (ISB). The OSCA category is fairly broad and can include dispersants, surface washing agents, sorbents, solidifiers, herders, de-emulsifiers, and bioremediants.

Provided in this report are:

- ART and OSCA product overviews;
- Descriptions of the federal (US Coast Guard (USCG) or US Environmental Protection Agency (EPA)) and state (California Department of Fish and Wildlife Office of Spill Prevention and Response (OSPR)) authorities in reviewing OSCA products, and federal and state roles in authorizing the use of various types of ART specific to actual incidents;
- Scientific research results from both testing and actual use of OSCAs or ISB on spills;
- Scientific research that explores the environmental or human health issues related to each product's use;
- The benefits or constraints presented by the use of each ART; and
- The updated status of each ART use plan.

This report concludes with a set of OSPR Findings and Recommendations related to each OSCA product category, and ISB. We address how our efforts have met previous Best Achievable Technology (BAT) goals related to the potential use of ART and offer recommendations for further development and refinement of ART research, response planning, and response policies.

Additional information on technologies addressed in this report may be found in the 2016 California Department of Fish and Wildlife (CDFW) OSPR Alternative Technology (ART) Report:

https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=136075&inline.

SECTION I: APPLIED RESPONSE TECHNOLOGY OVERVIEW

The forces of the natural environment influence spilled oil in ways that are impossible to fully control and difficult to accurately predict. The use of any oil spill response countermeasure, whether conventional or applied, assumes that use of one or several response approaches can offer a better environmental outcome than using one tool alone or none at all. As all response options have inherent limitations, responsible agencies must consider the best role of various Applied Response Technologies (ARTs) in supporting mechanical response, balance the benefits and consequences of each response action, and ultimately choose the combination of tools that provides the greatest resource protection.

There are two basic categories of ARTs:

1) The use of oil spill cleanup agents (OSCAs), such as dispersants, surface washing agents, sorbents, solidifiers, herders, de-emulsifiers, and bioremediants. Each of these is discussed in more detail in Section II.
2) The use of *in-situ* burning of oil (ISB). This topic is covered in Section III.

OFFSHORE RESPONSE

The most common and preferred approach in oil spill response, and the one considered in all first response efforts, is to use mechanical equipment such as boom and skimmers for containing and removing spilled oil. These tools typically recover less than 20 percent of oil spilled onto ocean waters (NRC, 2005). This may seem like an unacceptably low rate that could be improved by adding more mechanical recovery resources to the problem. However, the low oil recovery and removal rates using mechanical technologies are largely due to the low “encounter” rates of vessels as they slowly tow containment boom through an on-water oil slick or experience operational limitations due to high sea states. Even the most efficient skimming systems can only process the amount of oil that is delivered to them via the containment effort, and as they skim the collected oil, they generally recover an oil and water mix that is predominately water. Under the best of operating conditions, winds and currents can spread the slick faster than vessels can work. As sea state or weather conditions worsen, offshore water conditions become too rough to work in safely. The ability to contain the oil is significantly reduced once waves exceed 4-6 feet, which is not uncommon for California’s offshore waters. ISB of oil is also an offshore spill response option, but it too generally requires that oil first be gathered into a relatively thick layer before successful burning can occur.

A more controversial approach to move significant amounts of oil off the water surface is to use dispersants to deliberately and quickly move oil from the surface and into the large body of underlying water. A decision to use dispersants will bring its own set of environmental benefits and consequences that must be understood and weighed carefully well in advance of a spill response.

SHORELINE CLEANUP

There are also limits to how much oil stranded on and within various types of shoreline habitats can be feasibly and safely removed. On-shore mechanical recovery is limited when stranded oil becomes stuck on vegetation, beach bluffs, or constructed shoreline surfaces. Oil can become buried in sand and soil or stranded among rocks, making it difficult to find and remove without creating additional adverse effects to organisms and their habitats.

On-shore cleanup of spilled oil can take advantage of various ARTs. As with on-water spill response, mechanical cleanup is still the traditional and preferred response tool. Sorbents, surface washing agents, self-contained solidifiers, bioremediation, and ISB are specific ARTs that can play a strategic support role when added to the suite of on-shore cleanup techniques.

THE “NO RESPONSE” OPTION

Another approach to on-water or on-shore cleanup is to simply allow the natural forces of nature to proceed. No oil is removed from the environment, resulting in natural forces shifting the oil into different environmental compartments – volatile oil compounds evaporate, parts of the surface oil slick physically disperse or dissolve into underlying water or mix into shoreline sands, and the surface slick gradually breaks into smaller patches that drift away. If a slick is near or on a high energy beach, wave action can remove stranded oil from surface areas in a relatively short period of time. This approach is less practical in low energy areas (marsh, wetlands, tidal flats, lagoons, inland ponds and lakes) where the removal of oil is the result of degradation processes (e.g., photo-oxidation, biodegradation) and not wave energy.

SECTION II: OIL SPILL CLEANUP AGENTS

An OSCA is defined by the state of California as any chemical, or any other substance, used for removing, dispersing, or otherwise cleaning up oil or any residual products of petroleum in or on any of the waters of the state.

FEDERAL AUTHORITY

The EPA has primary responsibility for the listing of products on the National Contingency Plan (NCP) Product Schedule, regulated under Subpart J. An OSCA must be on the Product Schedule before it can be considered for use on a spill to federal waters. To be included on the Product Schedule, OSCA information addressing toxicity, efficacy, chemical composition, safety considerations, and application procedures must first be submitted to the EPA. If the product information is checked and considered by the EPA to be complete, the OSCA is added to the Product Schedule. The EPA is currently revising Subpart J; release date for the revision is unknown at this time.

Policies directing the use of all ARTs are in the Regional Response Team Region IX (RRT IX) Regional Contingency Plan (RCP). The current RCP has separate ART plans for: 1) dispersants, 2) ISB, 3) bioremediation, and 4) other OSCAs. All ART plans are currently in the process of review and revision, and the updates to each plan will be reflected in future updates to this report. The RCP applies statewide, and addresses oil spill threats to federal and state marine and inland waters. https://www.wildlife.ca.gov/OSPR/Preparedness/Fed-Region-Contingency-Plan)

All ARTs must be authorized by RRT IX in advance of their use. During an oil spill, the Federal On-Scene Coordinator (FOSC) can request RRT IX to approve the use of an OSCA. The National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator (NOAA SSC) and the OSPR ART Lead Technical Specialist (TS) assist the FOSC in consulting with the various trustee agencies, gathering incident-specific information on environmental resources at risk, and determining which (if any) ART use can be expected to result in the highest “net environmental benefit” when considered and balanced against all other available oil spill response options.

STATE AUTHORITY

OSPR reviews and licenses OSCAs pursuant to Government Code §8670.13.1. The licensing process gives OSPR the opportunity to review product information, including toxicity, efficacy, and degradation characteristics, in a non-emergency situation. The environmental benefits (and potential consequences) of product use are considered as part of the licensing process. During an actual incident, this information is available to responders to support planning.

Although it is possible to use an unlicensed product during a spill incident, this can only be done on an on-time experimental use basis. The use of an unlicensed product is considered if such use provides a result that cannot be obtained through use of an already licensed product.

OSPR is one of the members of RRT IX authorizing use of ARTs when considered for use in, on, or where they may affect state waters. Per Government Code §8670.7(f), and separate from his/her role on the RRT, the OSPR Administrator has an additional responsibility to review and approve the use of any ART for oil spills in, on, or threatening state waters. OSPR also reviews OSCAs under the California Fish and Game Code §5650 regarding otherwise non-toxic agents that might pose deleterious risks to the state’s trustee resources.

Depending on what changes are promulgated for the final revised Subpart J, the state may also change its licensing regulations and guidance to mirror the federal approach. If the federal approach falls short of what the state must require in the way of product licensing requirements, then there may be additional testing and thresholds requirements established at the state level for all OSCAs. After OSPR revises its licensing regulations and procedures (a process likely beginning in 2018), all OSCA manufacturers currently holding an OSPR license or exemption will be asked to reapply, incorporating any new EPA and OSPR testing requirements and data in their applications. OSPR will not charge a fee for review of the re-submitted license and exemption applications, although the applicant will still be required to pay for any required efficacy or toxicity testing needed to support the application.

DISPERSANTS

Dispersants cannot remove spilled oil from the environment, but they can move oil away from critical, long-lived, and sensitive resources that can be injured or killed by a surface oil slick; they do this by creating a diffuse plume of oil droplets that shifts into the larger space of the deep water below. The effectiveness of this method has been reported to range from near zero to 100 percent depending on the type of petroleum spilled, the dispersant agent used, and the tests used to estimate effectiveness (NRC, 2005).

The primary purpose of a dispersant is to “speed up” the natural (but slower) oil slick breakup and biodegradation processes by moving spilled oil from the surface of the water into the water column. Once treated oil enters the water column, it can be acted upon in a third dimension, and undergo quicker dispersion by the water currents, as subsurface water currents are typically stronger and more consistent than the winds that act on oil at the water’s surface. Dispersants break oil into smaller droplet sizes than those created by natural dispersion, and these smaller droplets stay in suspension rather than coalescing and re-surfacing. There is also compelling evidence that development of smaller oil droplets may increase the natural degradation rate of spilled oil by microbes in the water that readily use oil as a food source (Venosa and Holder, 2007; Campo et al., 2013).

Dispersant Properties

Initial dispersant formulations, developed in the 1950s, were primarily highly aromatic solvents, such as kerosene and non-biodegradable emulsifiers (NRC, 1989). These first generation dispersants, although effective in dispersing oil, were highly toxic and caused great ecological damage to the intertidal and shallow water biological communities. In the late 1960s, a second generation of oil spill dispersants was developed. These products had lower amounts of aromatic hydrocarbons and biodegradable emulsifiers with relatively lower toxicity. However, these dispersants were less reliable than their predecessors in dispersing oil and thus of questionable use to the response community (NRC, 1989). During the 1970s, the third generation of dispersants was developed. These are the commercial products available to the oil spill response community today.

The current NCP Product Schedule lists the oil spill dispersants registered for use in U.S. waters. The State of California has reviewed and licensed four of these products for use in state waters. It is the policy of RRT IX that any dispersant use in California offshore waters, even outside of state waters, will use a dispersant product that is both on the NCP Product Schedule and licensed by OSPR.

Dispersant Efficacy

The efficacy of a dispersant is primarily related to the physical properties of the spilled oil within the context of current environmental conditions at the spill site. Most data on dispersant efficacy are derived from laboratory or wave tank tests. A limited number of past field tests were conducted on controlled spills and “spills of opportunity.”

Operational effectiveness can be difficult to simulate in lab-scale settings, and hydrodynamic effectiveness cannot be tested in lab-scale systems or wave tanks. In principle, full-scale field studies can test hydrodynamic effectiveness, but this is difficult and not always done. Chemical effectiveness has been investigated in the laboratory, in wave tanks, and at sea, but various definitions of effectiveness and different measurement protocols can cause confusion when attempting to compare results (NRC, 2005).

Not all oils are dispersible or should be considered for chemical dispersion. For example, spills of refined petroleum products (e.g., gasoline, jet fuel, kerosene, and diesel) generally result in thin sheens that evaporate quickly; dispersants are not recommended for use on these types of spills. Based on lab tests with crude oils, the average effectiveness of dispersants, based on oil viscosity, is generally as follows:

Heavy crude:	1 percent	Light crude:	30 percent
Medium crude:	10 percent	Very light crude:	90 percent

As spilled crude oil changes through natural “weathering,” its viscosity increases, and with many types of oils (those with significant levels of asphaltene, aromatic and polar compounds), water-in-oil emulsions are formed. Both weathering and water-in-oil emulsions are impediments to dispersant efficacy. The weathering process removes compounds with which current dispersant formulations are designed to react, while water-in-oil emulsions create a foamy “mousse” that negates effective dispersant action.

Crude oil shipped through California marine waters is primarily of medium to heavy viscosity. This suggests that it would be impractical to rely on currently available commercial dispersants alone to clean up a significant crude oil spill.

Due to the weathering process and emulsion formation, the use of dispersants is typically limited to the initial spill response (12-72 hours), although some crude oils (e.g., Alaska North Slope) may remain dispersible for six days or more.

Additional efficacy testing of several dispersants listed on the NPC Product Schedule was ordered as part of the *Deepwater Horizon* (DWH) response. Details of this testing can be found in the 2016 OSPR ART Technology Report:
https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=136075&inline

Dispersant Toxicity Testing in Advance of a Spill

Testing dispersant and dispersed oil toxicity in an open ocean environment is not generally possible. Research has instead primarily focused on testing selected species through exposure to selected test solutions of known concentrations or dilutions, in a laboratory or wave tank setting where exposure conditions can be controlled and monitored. The goal of these studies is to be able to use the information gained from laboratory toxicity testing and generate results that can be extrapolated to an actual oil spill, where the setting in which organisms will be exposed to chemically dispersed oils is largely uncontrolled.

The predominant concern with a dispersant addition to spilled oil is that the application will result in the release of additional petroleum to the water column, in the form of both small oil droplets and a dissolved portion, elevating both oil-related acute and chronic toxicity to living natural resources. Field studies in the United Kingdom demonstrated that the addition of dispersants increased the water column concentration of oil within the upper five meters by 16-27 times over that found under an untreated slick (Lunel, 1994). Studies by Mackay et al. (1982) reported average dispersed oil concentrations of 41 parts per million (ppm) at one meter under a treated slick, thirty minutes after dispersant application, with concentrations falling to 1-2 ppm after three hours. Results from these studies indicate that dispersed oil concentrations typically did not exceed 1 ppm at a depth of ten meters (Mackay et al., 1982; Lunel, 1994; Aurand et al., 2000; NRC, 2005).

As the early life stages of fish and invertebrates are particularly vulnerable to oil spills, particularly the polycyclic aromatic hydrocarbons (PAHs) in oils (NRC, 2005; Logan, 2007), any spill-related research or models that help further assess the environmental impacts of oil or chemically-dispersed oil to fish and invertebrate eggs and larvae have particular value. In general, adding dispersants results in higher concentrations of Total PAH (TPAH) when compared to not adding dispersants. Modeled simulations of spill scenarios show that addition of chemical dispersant, in general, actually resulted in a moderate decrease in the fraction of eggs and larvae that were exposed above the selected threshold values.

The effect of the reported concentrations of dispersed oil on the water column community during real spills is difficult to determine. The literature contains several studies that have attempted to address the dispersed oil toxicity question, but because of different testing and experimental exposure protocols, the results of these studies are difficult to correlate to "*in-situ*" conditions. Results of the studies do clearly indicate that dispersed oil concentrations reported from the upper few meters of the water (Mackay et al., 1982) are sufficient to result in acute toxicity to many water column organisms for the first few hours following the addition of dispersant. The hydrocarbon concentrations below undispersed oil are also likely sufficient to cause acute toxicity in the upper meter or more of the water column. What remains unclear is the effect of dispersed oil deeper than the upper one to two meters of the water column, where dispersed hydrocarbon levels can decrease within a few hours to concentrations of 1 ppm or less.

The general factors that influence toxicity tests in the laboratory include test organism and life stage, the condition of the oil as tested (whether fresh or weathered), the method of test solution preparation, exposure conditions of the selected organisms to the test solutions, and the choice of an organism's response reactions to evaluate as part of the tests (NRC, 2005). Commonly used test organisms include fish (such as trout, smelt, sculpin, silverside, minnow, salmon, and bass), mollusks (such as red abalone, scallops, clams, oysters, and marine snails), crustaceans (such as copepods, shrimp, and crabs), annelids (worms), and algae. The choice of organism used will depend on a combination of factors including the potential risk of an organism being exposed to chemically dispersed oil, sensitivity of the organism (compared to other organisms) to dispersed oil, how well that species handles test conditions, and the relative ecological and economical significance of exposing that organism to dispersed oil during a real oil spill.

The choice of response parameters being evaluated for each organism undergoing the tests will depend on whether dispersant is being tested by itself (which can cause disruptions to membranes and general narcosis) or whether the solution being tested is dispersant mixed with oil (which can cause toxic effects through multiple pathways).

Mixing and “loading” energies affect the relative concentrations of oil and dispersant to which test organisms are exposed, so the method of preparing test solutions is very important. How test organisms are exposed can vary by the test apparatus (e.g., closed versus open systems), the exposure pattern (e.g., static or flow-through conditions, or spiked or continuous additions of toxicants), the exposure pathway (e.g., via water or food), the test duration, temperature, salinity, and buffering capacity. The test duration must be chosen carefully, as it can overestimate or underestimate the toxicity being simulated. Much of the literature on toxicity of dispersant alone and dispersant mixed with oil is based on typical static exposures of 48-96 hours, and while results from these tests provide data on the relative product toxicity, the results are criticized as potentially overestimating the toxicity of untreated oil versus chemically dispersed oil in actual spill scenarios (NRC, 1989; George-Ares and Clark, 2000). Based on these and other issues, OSPR and UC Davis initiated a 7+ year program, focused on developing more environmentally realistic dispersant and dispersed oil toxicity data.

Also in response to these concerns, the Chemical Response to Oil Spills Environmental Research Forum (CROSERF) was organized in 1994 by the Marine Spill Response Corporation (MSRC), the OSPR/UC Davis Dispersant Research Program, Exxon Research and Engineering Company, and The Texas General Land Office. The forum consisted of academic institutions from five universities within the US, as well as team members from industry; federal agencies including NOAA, Minerals Management Service (MMS), and EPA; and many international groups. The CROSERF adopted an OSPR/UC Davis designed declining-flow-through toxicity test protocol that used shorter exposure times and standardized water preparations (Singer et al., 1990). The purpose of this approach was to mimic real-world exposure regimes typically found in nature and thereby better characterize oil and dispersed oil aquatic toxicity (Aurand and Coelho, 2005). Significant toxicological information generated using the new CROSERF protocols addressed the relative toxicity of different dispersants (both alone and when mixed with oil) and the relative sensitivity of test organisms (Singer et al., 1998; Singer et al., 2001a; Singer et al., 2001b; NRC, 2005).

Results of testing programs of the past three decades indicate that third generation dispersants (including the Corexit and Nokomis products licensed for use in California waters) are significantly less toxic than previous generations of dispersants. Further, the test results indicate that these dispersants, by themselves, are significantly less toxic than the crude oils commonly transported through state waters (NRC, 2005).

What must also be kept in balance is the recognition, during both planning and response, of the following:

1) An untreated surface slick will continue to drift and spread over a larger area and for a longer time, exposing more animals to its effects;
2) The normal fate of some of the surface oil is to physically disperse into the water column, regardless of other response actions;
3) Use of dispersants in a smaller area of the ocean can limit some of the oil exposure that would otherwise occur to rare or highly sensitive species, fewer long-lived species will suffer acute affects and death, and the acute affects will primarily be to organisms that have short life spans and/or a large population, and whose lost portion of the population will more readily recover; and
4) Actual use of dispersant will follow practices that avoid direct spraying over or near wildlife aggregations, and even animals already trapped in the oil will be avoided to the greatest extent possible.

Dispersant Toxicity Testing as a Result of a Spill

Following the 2010 *Deepwater Horizon* (DWH) spill, the EPA did additional comparative efficacy, toxicity, and endocrine disruption testing on eight of the dispersants listed on the NCP Product Schedule (Dispersit SPC 1000, Nokomis 3-F4, Nokomis 3-AA, ZI-400, SAF-RON Gold, Sea Brat #4, Corexit 9500, and JD-2000), both alone and when combined with Louisiana Sweet Crude oil (LSC) (EPA(a), 2010; EPA(b), 2010; EPA(c), 2010). The main conclusions were:

- While the dispersant products alone (not mixed with oil) had roughly the same impact on aquatic life, JD-2000 and Corexit 9500 were generally less toxic to small fish (measured as LC_{50}, the lethal concentration at which 50% of the test organisms die), and JD-2000 and SAF-FON Gold were least toxic to mysid shrimp. Corexit 9500 was generally not more or less toxic than the other available alternatives.
- None of the eight dispersants tested, including Corexit 9500, displayed biologically significant endocrine disruption activity via the androgen or estrogen signaling pathways. All of the dispersants showed cytotoxicity in at least one cell type at concentrations between 10 and 1000 ppm.
- All dispersants alone were less toxic than the dispersant-oil mixture. Oil alone was found to be more toxic to mysid shrimp than the eight dispersants when tested alone. Oil alone posed similar toxicity to mysid shrimp as the dispersant-oil mixtures, with the exception of the mixture of Nokomis 3-AA and oil, which

was found to be more toxic.

- Initial oil-only tests for small fish were inconclusive, so retesting occurred. The additional data showed LSC oil alone to be more toxic to the silverside fish than the eight dispersants alone. Additionally, the oil alone had similar toxicity to the silverside fish as the dispersant-oil mixtures, with the exception of the mixture of Dispersit SPC 1000 and Nokomis 3-AA, which were found to be more toxic than oil alone.

While the environmental and toxicological effects of Corexit 9500 have been extensively researched in laboratory and wave tank settings, real-world knowledge of its use on actual spills was fairly rare until the DWH spill, when both Corexit 9527 and Corexit 9500 were used. Corexit 9500 is the more recently developed and less toxic formulation and was used more extensively once stockpiles of Corexit 9527 were substantially depleted.

With the exception of one proprietary component, the chemical compositions of Corexit 9527 and Corexit 9500 were identified in Safety Data Sheets submitted to EPA as required by Subpart J of the NCP, Sec. 300.915. As it became apparent that large volumes of dispersants were being used to combat the subsurface and surface oil spill, EPA requested and received a disclosure from the manufacturer of the proprietary component (i.e., dioctyl sodium sulfosuccinate, or DOSS). This allowed additional evaluations by NOAA and the Food and Drug Administration (FDA) of the components of these two most commonly used dispersants (Dickey and Dickhoff, 2011). Corexit constituents and FDA assessment of the risks they post to human health are listed in Table 1 of the 2016 OSPR ART Technology report: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=136075&inline

Relative to their evaluation of Corexit dispersants used in the DWH spill response for the Gulf of Mexico (GOM), the authors (Dickey and Dickhoff, 2011) provided the following statement:

> “In considering the potential for chemical dispersants to compromise the safety of GOM seafood, initial questions concerned the potential toxicity of dispersant constituents, their concentrations and persistence in the environment, their potential for bioconcentration in seafood species, and their disposition and persistence in seafood species. With the exception of dipropylene glycol monobutyl ether, the constituents of Corexit® dispersants are recognized direct or indirect food additives under prescribed conditions of use. Corexit® dispersants used to treat the DWH oil spill were rapidly and extensively diluted in GOM waters, and environmental concentrations estimated and measured, were commensurately low (i.e., ppb) when detected. The physicochemical characteristics and scientific literature indicate that the dispersant constituents are susceptible to chemical and biological degradation, and that the potential for bioconcentration and persistence in the edible tissues of seafood species is low. The modeling, experimental and field assessments performed during the response to the DWH oil spill, as well as ancillary literature, indicated that Corexit® dispersants did not pose a threat to the safety of GOM

> seafood during or after their use. Oil spills in different parts of the world are known to differ in the nature and extent of public and environmental health hazards entailed, and consequently response strategies are rarely the same. There are numerous dispersant formulations available or in development for mitigation of oil spills under different physical conditions. Future responders would benefit from a systematic assessment of less known dispersant constituents, and their fate in aquatic species."

The Chemical Aquatic Fate and Effects ("CAFÉ") database, created by Adriana Bejarano of Research Planning, Inc. and released to key response agencies in early 2014, compares all currently available research literature for dispersant toxicity and offers a searchable tool for use during oil spill response and response planning. http://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/response-tools/cafe.html

Following the DWH spill, substantial research funding was allocated to further examine the fate, effects, and toxicity of oil and dispersed oil in the aquatic environment (Coelho et al., 2013). A number of publications attempted to address these issues using laboratory testing and extrapolation procedures that were not fully reliable measures for those environmental assessments (Bejarano et al., 2014). One example (Rico-Martinez et al., 2013) serves to show how the use of incorrect laboratory testing approaches can severely limit the ability to reliably extrapolate the test results to meaningful real world assessments. Coelho et al. (2013) reported that the main technical issue with much of the post-DWH dispersant research, and its ability to support future dispersant use decision-making, is twofold:

1) Performing toxicity testing with complex hydrocarbon mixtures in seawater presents challenges due to the inherent difficulties in interpreting and quantifying exposure concentrations when the toxicant consists of compounds with varying degrees of volatility and water solubility. As a result, a reliable characterization of exposure during toxicity tests is critical to ensure correct interpretation of the results.

    - A standardized methodology must be used for preparing test solutions of oil and dispersed oil to ensure that test results are comparable among different research laboratories;
    - Toxicity tests must emphasize the quantification of actual oil exposure concentrations in terms of specific analytical measurements, namely the concentrations of Total Petroleum Hydrocarbons (TPH) and Total Polycyclic Aromatic Hydrocarbons (TPAH) in water;
    - A minimum list of target analytes must be identified and included in the chemical analysis of all test solutions so that the TPH and TPAH values can be compared among different test conditions (e.g., different species, different oils) and different research laboratories.

    This is necessary to ensure that differences in observed effects on test organisms are not erroneously attributed to differences in toxicity when they are actually a result of different oil exposure levels. The inherent toxicity of a given oil does not change when dispersants are added. Rather, the dispersant has effectively changed both the amount and location of organism exposure to the oil (i.e., making the oil more bioavailable to the organisms in question) by moving it from the water's surface to the water column. The real world utility of laboratory toxicity tests lies in the ability to compare concentrations of oil that cause impacts on laboratory test species with measured concentrations of oil and dispersants in the water column following dispersant use during actual oil spills, thus providing a way to predict likely impacts.

2) The second challenge with much of the post-DWH dispersant toxicity research was that many studies failed to put the research into the context of an environmental risk versus consequence analysis. Dispersants are used to combat oil spilled on open water to purposefully and strategically change the fate of the spilled oil. Trustee and response agencies clearly understand that when a decision is made to apply dispersants, even in a well-mixed open-water environment, there <u>will</u> be resultant short-term increases in water column exposure concentrations. However, when dispersants are properly used, these short-term increases (which persist for minutes to hours) are rapidly diluted to concentrations well below acute thresholds (McAuliffe et al., 1981; NRC, 1989; Wright et al., 1994; Coelho et al., 1998, Coelho et al., 2013).

Dispersed Oil Monitoring

Two types of dispersed oil monitoring are generally considered. One has to do with how effective the dispersant application has been on targeting, contacting, mixing, and dispersing a surface oil slick into the underlying water column; the other has to do with the expected acute and chronic effects of dispersed oil on sensitive species and life stages within and downstream of the operational area. These are summarized below.

The simplest and probably most readily deployable measures of effectiveness range from subjective visual observations to somewhat more technical fluorometry measurements, and are described in the Special Monitoring of Applied Response Technologies (SMART) protocols. The SMART protocols were developed by the NOAA and are most commonly implemented using trained personnel from USCG Strike Teams. Tier I (visual observation of effectiveness) can be conducted by trained observers other than those on the Strike Team. The current protocols are available from the NOAA web site:
http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/smart.html

Tier I SMART involves determining, based on visual observation only, whether dispersant has "successfully" mixed with the oil. Even this lowest tier of observation requires some experience and judgment on the part of the SMART observer. Tier I observations can be extremely helpful to the FOSC and RRT in determining whether dispersant approvals should be initially considered, or if already approved, how and whether they should continue or be modified to address changes in the on-going response. Tiers II and III of SMART monitoring use towed fluorometry arrays, which provide data on whether more material has moved into the upper water column after a spray operation. The fluorometer readings do not provide certainty that the additional material that might be detected in the water is from dispersed oil. However, coupled with Tier I observations, they can provide some good evidence of probable dispersion. Tiers II and III do not provide data on oil concentration, although if water samples are collected from various depths (e.g., 1m, 5m, 10m) below the treated slick, they can be later analyzed for oil concentrations.

An estimated total of 4.9 million barrels (about 206 million gallons) of oil was released during the DWH spill. Of that, it is estimated that burning, skimming, and direct recovery of oil from the wellhead removed 25% of it. Another 25% naturally evaporated or dissolved, and 24% was naturally (16%) or chemically (8%) dispersed. The residual amount of 26% remained either on or just below the surface as light sheen and weathered tar balls, washed ashore or was collected after it stranded on shore, or was buried in sand and sediments. Oil in the residual and dispersed categories is undergoing longer-term natural degradation (Lubchenco et al., 2010).

The FOSC and the Unified Command (UC) need to know whether dispersants are effective in dispersing oil. During DWH, SMART Tiers I-III were used to help address the effectiveness question. At the request of the U.S. government and BP PLC, research scientists and technicians from the Centre for Offshore Oil Gas and Energy Research (COOGER) and Fisheries and Oceans Canada (DFO) also conducted at-sea Laser In-situ Scattering and Transmissometer (LISST) monitoring operations with other scientific experts on board vessels to assist in a comprehensive environmental monitoring program. The SMART and LISST dispersant monitoring are designed to provide information in near-real-time. SMART and LISST dispersant effectiveness monitoring are not designed to monitor dispersed oil fate, effects, or impacts.

A total of approximately 2.1 million gallons of dispersant were applied during this spill. Of this total, 1.4 million gallons were applied at the surface and 0.77 million gallons were applied directly at the wellhead (Kujawinski et al., 2011). Two dispersants were used extensively: Corexit 9527 (surface applications only) and Corexit 9500 (use in both surface application and directly at the subsea wellhead). Almost all of the components of the two dispersants dispersed to non-detectable levels too quickly to be used as tracers. However, one component of both formulations, dioctyl sodium sulfosuccinate (DOSS), was detectable for up to a few weeks after application and was therefore the tracer used to chart the fate of the dispersant once it was in the water.

The bulk of elevated DOSS concentrations occurred in water depths between 1,000 and 1,200 meters and was attributed to dispersant injections at the wellhead. Data suggest that the surface and deep water dispersant applications did not substantially intermingle throughout the water column. All of the naturally dispersed oil and some of the oil that was chemically dispersed remained well below the surface in diffuse clouds where it was able to further dissipate and biodegrade. Analyses during the DWH response indicated evidence of diffuse clouds of dispersed oil between 3,300 and 4,300 feet in very low concentrations (parts per million or less). Oil that was chemically dispersed at the surface moved into the top 20 feet of the water column where it mixed with surrounding waters and began, as expected, to disperse and biodegrade (Lubchenco et al., 2010).

The DWH Oil Spill dataset, including more than two million chemical analyses of sediment, tissue, water, and oil, as well as toxicity testing results and related documentation, is available to the public online:
http://www.nodc.noaa.gov/deepwaterhorizon/specialcollections.html

As mentioned above, SMART and LISST cannot are not designed to provide information on dispersed oil fate and effects. The California Dispersed Oil Monitoring Plan (DOMP) (French-McCay et al., 2008) was designed in 2008 to fill this void. It provides background to the models used to more effectively quantify relative risks to wildlife at the surface versus plankton, small fish, and eggs/larvae that may be present in the upper water column during an oil spill and dispersant use. It also provides suggestions for field sampling before, during, and after a use of chemical dispersants to validate dispersed oil concentrations and movement behavior of the dispersed oil plume. The 2008 DOMP will be updated to incorporate lessons-learned from the DWH spill response and any benefits or improvements that can be gained from the extensive use of SMART and LISST during that spill. This update is anticipated to be complete by the end of 2018.

There is a very low potential for a large or sustained release of oil from California offshore platforms or their associated transfer pipelines. The wells, for the most part, have no or little positive pressure that could lead to a blow-out. All underwater transfer pipelines have shutoff valves. Because a subsea application of dispersants for spills in California is improbable, the fate of a dispersed oil plume that results from the surface use of dispersants is of greater interest to California oil spill responders and planners. The lessons-learned from the use of surface-applied dispersants during DWH are thus the most relevant to California use.

The fate of the surface-applied dispersant during the DWH response closely matched the planning assumptions used in California’s extensive Net Environmental Benefit Analysis (NEBA) planning. The effects on environmental resources from the large volume and sustained use of dispersants during DWH does not match the California planning assumptions; California planning assumes a much more limited (5-7 day) window of use, therefore targeting much smaller spills with correspondingly smaller dispersant volumes.

Dispersant Application Technology

The three primary modes of dispersant application are boats, helicopters, and airplanes (NRC, 1989). Fixed wing aircraft may be the only or best option for long distance or long duration dispersant operations. They are the primary planned dispersant application platform for large on-water oil spills in California. Planes like the C-130 provide the advantages of extended range, large dispersant carrying capacity, speed, and extended coverage.

There are many general factors important in the effective aerial application of dispersants, including the altitude of release, wind speed and direction, droplet characteristics, boom configuration, and swath width. Proper application targets the thickest and freshest areas of oil, avoids areas of clear water and sheens, and operates at a low altitude to minimize the drift of dispersant by the wind. Generally speaking, not all of the oil slick is suitable or chosen for dispersant treatment.

RRT IX Dispersant Use Plan for California

Nearly two decades ago, California recognized the value of the NEBA approach to support the dispersant use planning process. NEBAs, also sometimes called a Consensus Ecological Risk Assessment (Consensus ERA), were used by California coastal oil spill planning Area Committees (ACs) and their multi-stakeholder Dispersant Subcommittees. This was the means by which dispersant authorization zone recommendations were developed by each AC for their coastal area of responsibility. There was strong reliance on the dispersant efficacy and toxicity studies conducted by well-qualified and experienced dispersant researchers, using established standardized test protocols such as CROSERF. The zone recommendations developed through this NEBA and research-review process were accepted and implemented by the RRT IX in their Dispersant Use Plan (DUP) for California.

As a result of RRT IX acceptance of AC recommendations, the RRT IX DUP includes two dispersant zone types: 1) Pre-Authorization Zone; and 2) RRT Incident-Specific Authorization Zone. It specifies spill-specific conditions of dispersant use, FOSC decision-making flowcharts and checklists for working through the decision-making process in both types of zones, and provides forms, informational Job Aids, and Record of Decision templates. The DUP also provides information on dispersant use monitoring, wildlife monitoring, public outreach, and seafood safety. It articulates and provides records of communications to the RRT IX. The DUP is part of the Region IX RCP. The RCP (including all of the ART plans within it) are currently being updated, and will be re-posted to the OSPR web site when the updates are complete and finalized. Consultations under Section 7 of the Endangered Species Act (ESA) are also addressed in the DUP.

Any time dispersants are considered, the trustee agencies provide special attention to their potential effects on wildlife, the method of application, and monitoring during application. The application of dispersants over concentrations of marine mammals, sea turtles, birds, and other recognizable aggregations of sensitive species would be avoided. Areas where concentrations of wildlife have been observed during reconnaissance flights and other wildlife operations should be eliminated from operational plans when dispersant use is considered.

In areas where the dispersant use has not been pre-authorized by RRT IX, the NOAA SSC and the California ART Lead TS will help the FOSC and RRT IX decide whether there will be a reasonable expectation of achieving a net environmental benefit for a dispersant application in California offshore waters. The presence of an especially sensitive wildlife resource in the path of a spill trajectory might prompt or preclude the use of dispersants, even in a pre-authorization zone. The integration of pre-spill (baseline) data and reconnaissance information provide the response and trustee agencies with a common understanding and strategy to protect resources at risk during a response involving dispersants.

Following any RRT IX authorization to use dispersants, the ART Lead TS and/or NOAA SSC will work with the Dispersant Operations Section to make sure all RRT IX conditions of authorization and Best Management Practices (BMPs) developed by the trustee agencies are included in operational practice. As operations commence and continue, results from dispersant use monitoring (e.g., SMART program, wildlife spotters) will be acquired and reviewed to ensure the dispersant operation is effective and operating within the conditions of authorization. Dispersant operations will only continue while safe for operators and while providing a net environmental benefit.

Following are the conditions and expectations of California dispersant use:

- Zones currently being considered as RRT IX Pre-Authorized for dispersant use (the pre-authorization is granted by the RRT only to the FOSC) are only in waters no closer than 3 nautical miles (nm) from the nearest (mainland or island) shoreline, not within 3 miles of the CA/Mexico border, and not within the boundaries of a National Marine Sanctuary;
- During the breeding season period for marbled murrelet, the pre-authorization zone for application of dispersants is to be 5 to 200 nm (rather than 3 to 200m) from shore off the northern and central California coasts (CA/Oregon border to Monterey/San Luis Obispo county border);
- Dispersant application aircraft will not fly directly over offshore islands or rocks with significant numbers of roosting birds or hauled-out marine mammals. Caution will be taken to avoid spraying within buffer areas near congregations of marine mammals, sea turtles, surface aggregations of bait fish and brown sea nettles, or rafting flocks of birds;
- Subsea applications of dispersants, or use of dispersants at the water surface for more than 4 days, are not pre-authorized uses (rather, RRT IX incident-specific authorization is required);
- Dispersants cannot be applied to any spill of diesel or other similar light-weight and quickly-volatilizing Group 1 fuels or products (e.g., gasoline, kerosene, jet fuel, diesel), as doing so does not provide a net environmental benefit;
- Surface application of dispersant is not recommended in or over waters shallower than 60 feet;
- Dispersant use is unlikely to be authorized for use over waters >60 feet deep but within bays and harbors as dispersed oil droplets may bind to sediment and sink, rather than dispersing and spreading through the water column as intended. The USCG FOSC may also restrict approvals for use in bays near high human population centers as a means to further assure public safety;

- The SMART controller/observer should be over the spray site before the start of the operation. If possible, an approved marine wildlife observation specialist will accompany the SMART observer, scan the area for wildlife in advance of application, help direct the operation to the spray zone with no sighted wildlife, and follow along behind the application to observe wildlife that appear in the spray zone after spraying has begun;
- Additional considerations apply if the dispersant spray platform is a vessel, including vessel speed limits, stand-off distances from various whale species, and a requirement to have wildlife monitors on board each spray vessel.

Government Authorizations for Dispersant Use

Federal

As mechanical recovery is not always effective, the Oil Pollution Act of 1990 (OPA 90) included a mandate directing national and regional response teams to develop guidelines for other on-water response strategies, specifically the use of dispersants and ISB.

In 2002, the USCG changed its regulations for oil spill response capabilities to include minimum capabilities for dispersant application in all zones where dispersant use has been pre-authorized. This allows evaluation of factors such as dispersant effectiveness and effects, which are the major drivers in any response and trustee agency decision about whether or not dispersants should be used on a particular incident. This is an evaluation emphasis that is in addition to documenting the availability of dispersant application assets (dispersant, application aircraft and vessels, trained staff).

The U.S. Code of Federal Regulations (CFR; Title 33, Part 154) describes response plan development and requirements for facilities that handle, store, or transport Group I through Group IV petroleum oils; this includes vessels that transport oil to facilities within the inland, nearshore, or offshore areas where pre-authorization for dispersant use exists. Contingency plans must identify and ensure that sufficient volumes of dispersants on the NCP Product Schedule, application platforms and systems that meet stipulated performance criteria, and trained personnel are available and capable of commencing dispersant application operations at the site of a discharge within 7 hours and within 50 miles offshore following a decision by the FOSC to use dispersants. (Please refer to CFR Title 33 Part 154.1045 for additional detail on federal dispersant regulatory requirements).

The RRT IX DUP for California lists the location of all dispersant stockpiles, application platforms, and trained personnel that can respond for dispersant operations in California offshore areas.

State

In addition to authority to license and approve the use of OSCAs in state waters, the Administrator is also required to study the effects of dispersants and provide notice to the California Legislature whenever dispersants are used in California as well as a report on the reasons for and outcome of dispersant use for a given spill in California

(Government Code §§8670.12 and 8670.13.3). Government Code §8574.7(c)(6) calls for an expedited decision-making process for dispersant use in coastal waters and Administrator assurance that a comprehensive testing program is carried out for any dispersant proposed for use in California marine waters.

All California NEBAs to date have weighed the tradeoffs between efficacy and toxicity of liquid Corexit dispersants and other OSPR licensed liquid dispersants produced by Nokomis. The Section 7 consultations conducted under the Endangered Species Act (ESA) have been limited to current formulations and application systems for liquid Corexit and Nokomis products.

There are currently no plans on the part of the state or RRT IX to expand the use of dispersants, beyond continuing to seek all permits and permissions for the offshore (federal waters, 3-200 nm from shore) pre-authorizations as discussed above. Pre-authorizations are limited to the types of dispersants licensed by the State of California and on the NCP Product Schedule, and previously subject to NEBA analyses and ESA Section 7 consultations. Use of dispersants products not previously subject to NEBA or ESA Section 7 analyses may require further evaluation before they can be considered for pre-authorization or incident-specific use.

Use of Dispersants in California

Dispersants have not been used on an oil spill in California since one very limited application during the 1984 tank vessel *Puerto Rican* spill response outside of San Francisco Bay. Considerable scientific research has been conducted since then on both the efficacy and the environmental toxicity of the most commonly used and stockpiled dispersants. This has allowed for informed and rigorous environmental analyses and development of RRT IX policies for dispersant use that are the most protective of the habitats and species at greatest risk in any particular oil spill response. As such, dispersants have become an important spill response option that provides the potential to protect targeted sensitive resources under appropriate conditions.

Given the technical complexity and high degree of public interest in dispersant use, effective risk communication remains a critical component of dispersant use planning in California. OSPR will continue to work with federal partners in this arena, as the state’s lead trustee agency mandated to plan for possible use of dispersants while protecting living natural resources and their supporting habitats and ecosystems.

SORBENTS

Sorbents are materials that soak up liquids. Although the use of sorbent products is probably the second most commonly used oil recovery technique, they are not intended for recovering the main volume of a spill. Sorbents are usually considered auxiliary spill control materials used for the pickup of small volumes or sheens of oil that are not easily recovered by other mechanical means. They can be very valuable tools for shallow water habitats, such as marshes, and for spills of quickly sheening fuel oils, such as diesel (which is commonly more toxic than crude oil). Sorbents are also useful in harbor areas where large oil spill response organizations (OSROs) typically do not respond to smaller but more frequent fuel spills (but local harbor masters do). The widespread use of sorbents is generally limited by the intensive labor required and the amount of solid and hazardous waste generated. Since oil is often defined as a hazardous waste, any sorbent coated with oil (even a biodegradable sorbent) would also be considered a hazardous waste.

Sorbent materials may be sourced from natural materials, or be made of created synthetics. They can come in many forms including sheets, pillows, socks, sweeps, clusters (pom-poms), booms, and loose particulates. Several specific properties are considered advantageous for sorbent materials. A sorbent should be oleophilic and hydrophobic, it should pick up oil quickly, retain it without significant “re-sheening”, and should sorb a large amount per unit weight of sorbent. It should be easy to apply and recover as well as strong enough to be handled without coming apart. Sorbents used on water should be able to take on large amounts of oil without sinking. Cost-effectiveness and reusability may be important considerations. Since no product exists which can boast all of these advantages, sorbents will be reviewed for specific advantages and disadvantages based on product type.

Natural Sorbents

These products are plant or animal based (such as straw, peat, saw dust, wood chips, cellulose, feathers) or mineral based (such as clay, perlite, vermiculite, volcanic rock, glass wool). They are often used because they are abundant in nature or are waste products from some other industry. Most plant- or animal- based sorbents can pick up from 1-10 times their weight in oil and some have even higher ratios (Schulze, 1993). Generally, plant-based products must be treated to be oleophilic or they would also sorb water and may eventually sink. One example of such a product is wood chips, which can become waterlogged and sink if they are not coated in a way that allows them to instead remain afloat and absorb oil (coating materials may be evaluated as part of the OSPR licensing process). Some natural products, such as peat moss, are given special consideration if they are not pH neutral.

Mineral-based sorbents may sorb about 4-8 times their weight and occasionally up to 14 times their weight in oil (Schulze, 1993). Some of these materials can be difficult to apply because they are light and blow in the wind if broadcast. Others are hazardous to apply and require operators to wear breathing masks. Some mineral-based sorbents sink and therefore would not be appropriate for on-water use. The advantages of this class of sorbents are that they are abundant and inexpensive.

Since most natural sorbents come naturally as granular or loose materials, collection can become a problem, especially when spread on water. It is the policy of both the RRT IX and OSPR that, to the greatest extent possible, materials deployed to recover spilled oil are to be collected after use. As a result, sorbents are generally enclosed in mesh or netting when used on water.

There have been proponents for the use of other types of inexpensive sorbent boom and mat material (e.g., pet or human hair, other cellulose products such as hay, kenaf, bagasse), but these generally sorb more water than oil and soon sink below the surface. Hay can introduce seed that could be considered invasive depending on where and how it is used, and hair may potentially and unnecessarily introduce additional skin oils and residual chemicals into the spill environment. Any product used should be pH neutral, seed free, and self-contained for use on water. The State of California and the RRT IX may approve other products or forms of use depending on the exigencies of any particular oil spill response.

Synthetic Sorbents

These products include man-made polymer materials, such as polyurethane, polyethylene, polypropylene, nylon fibers, and urea formaldehyde foam. Synthetics are excellent for recovering small quantities of oil floating on the water. They are more effective, generally do not pose leaching concerns, are readily available, can be specially fabricated, and are strongly preferred. Synthetic sorbents typically sorb from 5-20 times their weight in oil and some foam sorbents have a sorbency ratio of as much as 40 to1 (Schulze, 1993). Synthetics can be strong enough to be used several times. The pore size of foams can be controlled over a wide range, allowing their use on oils of most viscosities. They store well (relatively small volume) and do not deteriorate, as long as they are not exposed to sunlight. The more common types are continuous materials that make them easier to deploy, recover, and use as a sweep. Some foam products can be re-used many times. Synthetic sorbents also have the advantage of being manufactured and available in many locations, so re-supply is not an issue.

Most natural sorbents packaged in an open mesh form can be expected to be weakened after a prolonged exposure to spilled oil. Further, when they have become saturated with highly viscous oil, they will tend to sag, tear, or come apart when they are lifted from the water. Conversely, some synthetic sorbent materials have a more continuous fabric-like construction (e.g., pom-poms and snare boom) that show no weakening after prolonged exposure to highly viscous oil. As a result, these are popular products for recovering highly weathered crude oils and mousse (Schulze, 1993).

Synthetics have a much higher sorbency ratio than natural sorbents, but several issues should be noted. Synthetics, in addition to not being biodegradable, are generally much more expensive than natural sorbents, and it may not be practical to use them in quantity. Some forms of the materials may not be available for use in the field (i.e., not available as self-contained for use on water) or not available in commercial quantities. Some of the highest performing synthetic materials, such as polyurethane foam, may not be practical for wide use in the field. Finally, some of the highest performing synthetic materials may present disposal issues.

OSPR-Sponsored Scientific Study

A report released in 2009 as part of the OSPR Scientific Study and Evaluation Program (SSEP) evaluated several particulate sorbents as oil spill response tools (Whiting et al., 2009). This study compared ten oil sorbent products made of peat moss, agricultural cellulose, recycled material cellulose, mineral dust, and polymer plastic. They were evaluated for their ability to adsorb and/or absorb Alaska North Slope crude oil and thereby reduce the immediate and longer-term potential of oiling birds and fur-bearing animals as well as minimize contamination of shore vegetation. The results of this study are available in the 2016 OSPR Art Technology Report: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=136075&inline

Recycling and Waste Disposal

One of the major disadvantages of using almost any sorbent material is the large amount of both solid and hazardous waste that is generated. In the *Exxon Valdez* spill, where only four percent of the spilled oil was recovered, approximately 33,000 tons of oily solid waste was generated (Carpenter et al., 1991). As stated previously, since oil is often defined as hazardous waste, even a biodegradable sorbent coated with oil may be considered hazardous waste.

One way to reduce hazardous and solid waste generation would be the continued development of reusable sorbents. Although many synthetic sorbent pads can currently be reused, the process of removing the oil from the sorbent can be cumbersome, making reusability more frequently a perceived rather than a real benefit. Process improvements currently being offered by some synthetic sorbent providers could greatly increase the efficiency and potential utility of reusable sorbents as part of cleanup operations.

SURFACE WASHING AGENTS

The principal use of surface washing agents (also sometimes referred to as beach cleaners or shoreline cleaning agents) is to lift stranded oil from surfaces (primarily oil stranded in intertidal areas or on constructed surfaces) and transfer it back onto the water surface where it can be recovered by on-water recovery methods. These agents should not act to further disperse the oil into the water (Clayton et al., 1993; Clayton, 1993).

Presently, there are two surface washing agents licensed for use in California: CytoSol, and Accell Clean SWA. Both products are considerably milder than conventional detergents, are safely used in the agriculture and dairy industries to wash edible produce and dairy cows, are safe to use (as instructed) on oiled surfaces, and would allow for release and recovery of oil that might otherwise become buried or stranded.

Efficacy

The effectiveness of a surface washing agent may depend on many factors (Walker et al., 1999): 1) properties and chemistry of the spilled oil; 2) composition of the cleaning agent; 3) type of substrate that is oiled; 4) how the agent is applied; 5) ratio of the amount of agent used to the amount of oil to be cleaned; 6) air temperature; 7) water salinity; 8) time required for “soaking” before wiping down oiled surfaces or flushing with water; and 9) field treatment parameters including flush water volume, pressure, and temperature.

It can be difficult to conduct lab-based efficacy testing of surface washing agents (Clayton, 1993) and, as a result, neither the EPA Product Schedule nor OSPR OSCA licensing requirements currently require (or offer a protocol for) lab-scale efficacy testing of surface washing agents. Future surface washing agent efficacy protocols incorporated into the NCP Product Schedule Subpart J revisions may be based on earlier protocol update work conducted by EPA staff (Koran et al., 2005; Koran et al., 2009).

Environmental Considerations

Recommended uses of a surface washing agent will depend on the oil spill environment (e.g., land, moving water, still water, surface oil, buried oil) and whether the surface being cleaned has living organisms attached to it. Some general considerations include the following:

- Protect the area surrounding the treatment zone with hard and/or sorbent boom, to allow capture and recovery of re-surfaced floating oil;
- Use spray-on/wipe-off application approaches whenever possible to minimize runoff (may not require RRT IX or OSPR Administrator approval if no runoff).
- Mix product with ambient water, at recommended dilution;
- Use with low-pressure flooding and/or cold or warm water may be safe in most cases, even on surfaces with attached living organisms (e.g., intertidal cobble, pier pilings). Use with high-pressure or hot water should be limited to areas where there are no attached living resources (e.g., ship hulls and equipment cleaning, seawalls, and rip rap above high tide line). Depending on spill location, this use will require RRT IX and OSPR Administrator approval;
- Use for *in-situ* beach sand cleaning can be considered if catchment trenches or pools are established and floating oil is recovered. Depending on the spill location, this use will require RRT IX and OSPR Administrator approval; and
- Surface washing agents can be used *ex-situ* (e.g., in pools, roll-off bins, truck-based systems, constructed sand-washing structures) without additional RRT IX or OSPR Administrator approval for the product, although additional permissions from other agencies may be necessary (e.g., for heavy equipment access to beach, creation of temporary facility pad sites). State Water Board rinse water quality and other discharge thresholds and conditions will apply.

Operational Considerations

Surface washing agents can be used alone (oil removal results from wave energy), applied with mechanical beach washing equipment, or used with pressure washing equipment.

When truck- or facility-based systems are used for cleaning, oily sand is removed from the beach by earth moving equipment and deposited into a sand cleaning machine. The machine (which may just use warm water, or warm water plus a washing agent), strips the sand of oil and takes it through a series of rinses, and then the cleaned sand is removed and stockpiled in the high intertidal area until it is placed back on the original beach. The advantage of onsite truck or facility based sand cleaning is that the sand is more thoroughly cleaned, and as opposed to excavation of sand for disposal, this process returns clean sand of identical grain size, color, and type to the beach of origin.

SOLIDIFIERS, ELASTICITY MODIFIERS, AND GELLING AGENTS

Solidifiers turn oil into a more cohesive or solid mass, and thus capture and retain oil. They are usually available in dry granular form (Walker et al., 1994) for use either in a loose and broadcast form, or as a more easily recoverable self-contained product (e.g., boom, sock, pillow or pad). Unlike sorbents that physically soak-up liquid, the solidifiers bond the liquid into a mass with minimal volume increase. When the product is used in a self-contained form, the oiled mass is easily recovered. The bonded material also eliminates dripping (common with sorbents) and thereby minimizes re-sheening, residue, or cross-contamination of otherwise unoiled areas.

Gelling agents, a sub-class of solidifiers, are usually two or more compounds applied as separate products that react with each other and the oil to form a gel-like structure (Walker et al., 1994). The mechanical strength of gels is weak, thus they can be broken down and the oil returned to its original liquid state.

The state currently has one licensed liquid gelling agent (Elastol) and two particulate solidifiers (CIAgent, ClearTec Rubberizer). CIAgent and ClearTec Rubberizer are the only two solidifying products that come in self-contained forms for use on spills to, on, or near open waters. Both CIAgent and ClearTec Rubberizer come in a variety of boom diameters and pillow forms and would have greatest utility on: spills of light-medium oils and sheens; for upper water column capture of suspended oil; in sensitive habitats (marshes, wetlands, mudflats) for collection of re-sheening oil; and for secondary containment and capture of oil in sandy beach (pre-dug) trenches or dry creek beds.

Only the ClearTec Rubberizer does not need any further RRT IX approval before use in a self-contained form, although as with any sorbent or particulate solidifier product, use in a loose and broadcast form is limited and would require RRT IX and OSPR Administrator review and authorization before use.

Efficacy

The effectiveness of a solidifier is based on the amount of product and time it takes to "fix" a given volume of oil. Less effective products require larger amounts to solidify oil. Between 13 and 44 percent by weight of a solidifier product was required to solidify Alberta Sweet Crude over a 30 minute period (Fingas et al., 1993). Fingas also found that the laboratory-measured application rates are much higher than the manufacturer recommended rate. In one large scale field test, double the laboratory-measured rate was required to solidify the oil. Effectiveness of liquid gelling agents is likely to decrease for emulsified, weathered, thick, or heavy oils due to difficulties in mixing (Walker et al., 1994).

Environmental Considerations

Solidifiers have relatively low toxicity or no toxicity (Walker et al., 1994). The primary environmental concern is the fate and secondary effects of (1) treated but unrecovered oil and (2) unreacted product. Some loose particulate products may be considered a micro-plastic, meaning unrecovered product could pose a persistent presence in the receiving environment. There is also a concern that some products, used in loose form, could be perceived by birds or fish as food. Ingestion of particulate solidifiers, even if non-toxic, could give the fish or bird a sense of fullness that could lead to starvation.

Secondary environmental concerns of using a solidifier in a loose and broadcast form are related to (1) physical disturbance of habitats during application onto stranded oil and (2) smothering. Workers would have to enter the treatment area twice - once to apply the product and again to recover the solidified oil. Repeated foot traffic likely disturbs soft substrates, which are characteristic of important mudflat and marsh habitats. Extreme care would be needed to prevent trampling of vegetation and epifauna. At the recommended application rates, large amounts of the product would have to be applied to shorelines; in this scenario, product alone could smother intertidal fauna and flora (Walker et al., 1994).

Operational Considerations

Use of solidifiers in self-contained form allows for relatively easy use and collection; oiled solidifier boom or pillows attached to a line can be easily retrieved using conventional equipment and strategies. Some manufacturers suggest their products can be wrung out and re-used, or oiled boom can be burned as fuel.

Use of loose particulate forms of solidifiers has potential for use in smaller, calmer and relatively controllable spill settings (e.g., shallow waters of marshes and harbors) or potentially applied to the edge of a slick to provide a solid barrier functioning somewhat like containment boom. However, wide-scale use of loose solidifiers is limited by the potentially large amount needed and the inconsistent application rates or mixing that can result with solid, semi-solid, and liquid oil (Walker et al., 1994).

Some available liquid products require the mixing of two or more components. This could prove to be almost impossible for large, uncontrolled on-water spills. Also because a gelled oil is structurally weak and may be difficult to recover mechanically (hence requiring manual recovery), use of liquid gelling agents may be very limited for on-water oil spills.

The possibility of using of liquid gelling or loose solidifying agents in a ruptured vessel or tank is also challenging for several reasons. A lack of capacity and access in the ruptured tank may prohibit the addition and mixing of the required large volume of gelling or solidifying agent. Assuming successful mixing, if the gelled product somehow escapes to open water, it might elude subsequent capture. Alternatively, if the gelled product remains contained, the resulting solid or semi-solid mass may not be extractable, leading to loss of the vessel.

HERDING AGENTS

Spilled oil spreads out very quickly to form thin films tenths of a millimeter thick. This thinning makes it difficult to contain and collect the oil by mechanical means, or to thicken it into a layer deep enough to support ISB.

Chemical herding agents work by exerting a spreading pressure on the water surface greater than the oil slick. When used in conjunction with conventional containment and recovery devices, herding agents help prevent oil from spreading (Dewling and McCarthy, 1980). Optimal uses of herding agents include controlling slicks under docks or piers where conventional equipment cannot reach, and in harbors where the equipment can be pre-staged and ready to use early in a spill (Walker et al., 1994).

Herders may also be effective in keeping shallow water slicks pushed away from contacting sensitive marshes. Herding agents are not a substitute for booms but may be used for short-term protection and enhanced recovery where deploying booms could cause more damage or be of limited effectiveness (Walker et al., 1994).

Recent studies (Buist et al,, 2010; Buist and Meyer, 2012; Buist et al., 2013; Lane et al., 2012; S.L. Ross, 2015) have evaluated the use of next-generation chemical herders to thicken oil slicks (as an alternative to containment with fire boom) for ISB operations in icy Arctic waters. While this research may not seem applicable in supporting an ISB operation in California, lessons learned related to open-water use of herders, or use on spills in icy lakes in California, will have direct value.

There are currently no chemical herders licensed by the state.

Environmental Considerations

Herding agents are applied directly to the water surface and not to the oil. They do not disperse the oil or increase its solubility. Thus, the greatest environmental risk is the aquatic toxicity of the product to neustonic organisms (those in the top 2 centimeters of water) and contact toxicity to intertidal vegetation. Acute toxicity of these products is of concern only under special conditions, such as in very shallow waters with limited flushing rates and abundant organisms in early life stages. Currently, there are no data on the contact toxicity of these products to vegetation.

Efficacy and Operational Considerations

Herding agents are applied in small quantities to the perimeter of a slick. Application is by spray systems which are hand-held, vessel-mounted, or mounted in fixed-wing aircraft or helicopters.

Even under favorable conditions, achieving proper application can be problematic (Walker et al., 1994), although recent tests in the Arctic with aerial application seem positive. More herding agent is not always better, and over-application can result in decreased effectiveness or negative effects, such as pushing oil away from recovery devices and sorbents.

Use of chemical herders for a California offshore oil spill response may be limited until herders are developed that can herd and sustain a slick under open-ocean conditions of large waves, swells, or heavy chop. Use of herders, in combination with containment and sorbent boom within more restricted areas (harbors, marinas, lagoons, estuaries, lakes, ponds) should be further explored.

DE-EMULSIFIERS

One potential approach to extending the window of opportunity for the use of dispersants or ISB is through the application of de-emulsifying agents, which could depress the formation of water-in-oil emulsion, or break an existing emulsion.

Although de-emulsifying agents have been used in field oil production for many years to prevent or break emulsions formed during the initial extraction of crude oil from the ground, there is little information on their use during on-water oil spill response.
A significant obstacle in the use of the de-emulsifying agents is commercial availability. There are no de-emulsifiers listed on the current NCP Product Schedule, and none have been reviewed or licensed by the state.

Most of the oils produced in California, and several of those transported through it, tend to emulsify relatively quickly, so additional research into the efficacy (and possible hazards) of using de-emulsifiers to support or prolong the use of either dispersants or ISB is very relevant to the California oil spill planning community, as are further tank studies of the general ignitibility of California-produced oils.

On-water use of de-emulsifying agents will require additional research before de-emulsifiers can be considered as a standard oil spill response tool. Work needs to continue on developing standardized methods for measuring emulsion properties and testing the efficacy and toxicity of de-emulsifying agents.

There are currently no de-emulsifiers licensed by the state.

BIOREMEDIANTS

Once oil enters the environment, oil-eating bacteria and other microorganisms begin to naturally alter and break down the contaminant into materials that include fatty acids, carbon dioxide, and water. Biodegradation is a natural process in the weathering of spilled oil. The rate of the process is controlled by several factors including temperature, oxygen levels, and available nutrients (Bragg et al., 1992). Bioremediation does not increase the ultimate extent of hydrocarbon degradation, but only the rate of biodegradation while easily degradable hydrocarbons are present. Some oil compounds are resistant to microbes, especially the higher molecular weight PAHs and the polar molecules containing nitrogen, sulfur, and oxygen (Atlas and Bragg, 2009).

Once the more easily degraded components are removed from the oil through weathering or other degradation processes, the continuing biodegradation of the remaining weathered oil residues is no longer limited only by nutrient availability, and the biodegradation rate naturally slows. Most bioremediation products contain primarily nutrients (fertilizers) to support native microbes. Others may also contain additional microbes, enzymes, surfactants, or preservatives.

There are three principal areas where the use of bioremediation has been considered: On-water, rocky or sandy intertidal regions, and marshes and mudflats.

Efficacy

Bioremediation may increase the rate of petroleum degradation by as much as threefold (Bragg et al., 1992). Results reported by other authors (Hoff, 1991) suggest the actual rate of bioremediation in the rocky intertidal habitat may be highly variable and differ significantly from area to area. It has been suggested that if the biodegradation rate cannot be accelerated by at least a factor of 2, it may not be worth considering (citations within Atlas and Bragg, 2009).

Lab-based efficacy testing of bioremediants is required for listing on the NCP Product Schedule. Currently, no bioremediant toxicity tests are required (although this may change when the EPA completes its updates to Subpart J). There are also currently no scientifically reviewed and supported testing protocols that can be used for field-based bioremediant efficacy testing in advance of a spill. Estimating bioremediation efficacy in the field is very difficult to determine due to the variability of the process over a study area and the difficulty in quantifying changes in petroleum concentrations.

Environmental and Operational Considerations

Bioremediation is typically useful on moderately to heavily oiled substrates (after other techniques have been used to remove as much oil as possible) and on lightly oiled shorelines where other techniques are destructive or ineffective. It is most effective on diesel-type and medium oils and least effective on thick oil residues. Bioremediation is not effective in removing oil from poorly oxygenated areas, such as below the surface of the intertidal sediments. Before bioremediation treatment is considered, the extent to which the chemical constituents of spilled oil remain after initial volatilization and weathering must be assessed. For example, bioremediation should not be considered for gasoline spills, which will be completely removed by evaporation in faster time frames than by microbial degradation (Walker et al., 2000). Guidelines for the use of bioremediation are available (Zhu et al., 2001) and some examples of their use in previous oil spill responses are further discussed in the 2016 OSPR ART Technology Report: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=136075&inline

Rocky and Sandy Intertidal Applications

The addition of microbial nutrients to the intertidal substrate may present a threat to the existing environment by introducing additional contaminants (e.g., heavy metals) and producing toxic materials such as ammonia (U.S. Congress, Office of Technology Assessment, 1991). Further, the physical application and monitoring process may excessively disturb or damage the existing biological community.

In addition to nutrients, some bioremediation products can contain strains of microorganisms known to degrade petroleum; there is little evidence that "seeded" bacteria have a significant effect on the rate of biodegradation. Conversely, there is evidence that native microorganisms in marine intertidal habitats will quickly out-compete introduced organisms and be the responsible agent for any significant petroleum biodegradation.

Marsh and Mudflat Applications

Marshes and mudflats are sensitive environments which are easily impacted by physical and mechanical oil spill cleanup techniques. For this reason, the less intrusive bioremediation process is a potentially important cleanup tool for oil spilled in soft substrate habitats. However, bioremediation may not be necessary in marshes, wetlands, or mudflats if high concentrations of nutrients are normally present and therefore not a limit to native bacterial growth and oil biodegradation processes. Other controlling factors, such as the availability of oxygen, may be more significant in the marsh/mudflat environment than is the addition of nutrients or additional microbes (Hoff, 1991).

Shoreline Use of Bioremediants Containing a Surfactant

Several bioremediant products contain some form of surfactant because (as with surface washing agents and dispersants) this provides a means for oil to be broken into small particles that are then more amenable to microbial biodegradation. However, use of surfactant-containing products on shorelines would need additional incident-specific review before use to evaluate potential secondary dispersant effects.

On-Water Application

Some bioremediant manufacturers have proposed their product for on-water application. The current reluctance to use a bioremediant in this manner is primarily due to the emergency nature of an on-water oil spill response where the intent is to expedite the removal of spilled oil. In contrast, bioremediation typically works in a time frame of weeks to months and thus is not generally considered or used as a first response tool, but rather considered for later stages in an oil spill response. Further, volatile components of crude oil, those components typically lost during the initial stages of a spill, are toxic to most oleophilic bacteria and must evaporate before the biodegradation process can begin (Hoff, 1991).

The use of bioremediation in open water has also received little consideration from agencies and other oil spill responders due to the lack of testing data. Research is currently underway, funded through the Oil Spill Research Institute, and should be informative for future discussions.

Government Authorization

Following EPA’s Subpart J revision, it is anticipated that there will be additional tests and toxicity thresholds that will need to be met by all categories of OSCAs, including bioremediants, to gain or retain future Product Schedule listing.

SECTION III. *IN-SITU* BURN

ISB is the combustion of spilled oil on water or land. Burning has distinct advantages over other oil spill countermeasures. It offers the potential to rapidly convert large quantities of oil into its primary combustion products while leaving a small percentage of unburned residue byproducts (Evans et al., 1992). The combustion products are then generally readily dispersed by atmospheric forces to inconsequential levels beyond 500 meters from the burn site. ISB concerns typically involve worker and public safety related to the nature of the combustion products, their atmospheric dispersion, and the principles governing the combustibility of oil on water (Evans et al., 1992).

Marine on-water ISB has been a considered response option since the late 1960s, when it was first tried during the 1967 *Torrey Canyon* oil spill. However, the first large-scale and successful use of ISB on water was during the 2010 DWH oil spill. On-water oil spills that occurred before the 2010 DWH spill, where ISB was used, include (Mabile, 2013):

U.S.	*SS Sansinema* (1976), *Argo Merchant* (1976), Buzzard's Bay (1969, 1977), *Exxon Valdez* (1989), *New Carissa* (1999), DWH (2010)
Canada	McKenzie River (1958), *Arrow* (1970), Nipisi (1976, 1982), *Imperial St. Clair* (1979)
S. America:	*Aegean Captain* (1979)
Overseas:	*Torrey Canyon* (1967), *Othello* (1979), *Castillo de Bellver* (1983: unintentional), *Haven* (1991), Kolva River (1994)

The 2010 DWH oil spill was the largest use of on-water ISB. Estimates of the total amount of oil burned, in 419 burning events, range from ~220,000 – 310,000 bbls (9,240,000 – 13,020,000 gallons) (Allen, 2011). Even though this represents only 5% of the oil spilled during this event (Federal Interagency Solutions Group, 2010), it is equivalent to the entire amount spilled during the 1989 *Exxon Valdez* spill. The DWH ISB operation provided a safe and successful removal of a significant amount of oil.

Past inland burns (these occurred outside California) of mainly crude oil have been conducted mostly in marshes and open fields (Gonzalez and Lugo, 1994). Nearly half of past burns of a known volume of spilled oil were for quantities of less than 1500 liters (396 gallons). Burning, especially of small spills, is routinely conducted in some states, but there is often little documentation available other than the fact that the oil was burned (Zengel et al., 2003; Dahlin et al., 1998).

EFFICACY

Although the efficiency of ISB is highly dependent on a number of physical factors, this technique is potentially highly effective in dealing with a large spill at sea and in removing large quantities of oil from the water before it comes ashore (S.L. Ross Environmental, 1990). Past laboratory studies demonstrated burn efficiencies of 54-90 percent (Benner et al., 1990; Brown and Goodman, 1986).

Laboratory tests have shown density to be a reasonably good predictor of success for ISB of light oils (McCourt et al., 2001). Burning success with oils of intermediate density was varied, but showed promise for some types of California crude oils. Other California oils in offshore oil fields may prove impossible to burn.

The US Department of the Interior-Minerals Management Service (MMS) has funded ISB studies since the 1980s, and full-scale field evaluation of ISB on the open ocean was conducted by the MMS and Environment Canada (as well as 48 other agencies) in 1993 as part pf the Newfoundland Off-shore Burn Experiment (NOBE). Findings from the NOBE burns indicate greater than 99 percent efficiency (Fingas, et al., 1995).

Test burns conducted in the first days of the 1989 *Exxon Valdez* spill in Prince William Sound, Alaska resulted in the burning of approximately 15,000 to 30,000 gallons of Prudhoe Bay crude oil, at an estimated efficiency of 98 percent or better (Allen, 1990).

Additional ISB-related testing currently underway are exploring the use of natural materials to help stabilize an oil slick and serve as a wicking agent for burning oil (Bonheyo, 2017), and the use of materials that create higher burn temperatures that may result in lower soot and burn residue production (Hansen, 2017).

ENVIRONMENTAL CONSIDERATIONS

Air Monitoring/Testing in Advance of a Spill

The production of copious amounts of heavy smoke over the course of an oil burn is both unsightly and a potential health threat to oil spill responders or the general public. Airborne components of burn by-products were the subject of previous intense study in both small- and large-scale burn experiments. Despite the highly visible character of smoke generated by the burning of oil (Evans et al.,1988a, 1988b) determined that only about ten percent of the original amount of a crude oil was converted into smoke during combustion.

Burning crude oil results in combustion products that are irritating or toxic, including carbon monoxide (CO), carbon dioxide (CO_2), sulfur oxides, nitrogen dioxide (NO_2), various polycyclic aromatic hydrocarbons, acid aerosols such as sulfuric acid, aldehydes, and acrolein (ATSDR, 1991). Quantitative analytical data from the NOBE research showed that these emissions from *in-situ* oil fires were below health concern levels beyond about 150 meters from the fire, with very little detected beyond 500 meters.

Many human health experts feel that the most significant human health risk resulting from ISB would be inhalation of the fine particulate material (PM) that is a major constituent of the smoke. It has been well-documented from long-term studies in exposed human populations that PM_{10} (10-micron size particles) presents a significant health problem. The extent to which these particles would present a health risk during a burn would depend on the concentration and duration of exposure (ATSDR, 1991).

Both the EPA and California Air Resources Board (CARB) have established particulate thresholds for PM_{10} and $PM_{2.5}$; the CARB threshold is the more stringent.

Air Monitoring/Testing as a Result of a Spill

The air monitoring that occurred during the DWH oil spill assessed (1) air impacts from volatile gases related to the spilled oil itself versus those from ISB and (2) potential human health impacts from volatile gases or particulate matter (soot) to either the response personnel or to the general public (Schrader, 2010; EPA, 2011; Middlebrook et al., 2012). Air monitoring early in the DWH response showed particulate levels near the ISB were not an issue (Schrader, 2010), but air was periodically monitored by the USCG Atlantic Strike Team using the SMART protocols to document that the plume did not exceed the established air quality standard of 150 µg of PM_{10} per m^3, averaged over a 12-hr period. The EPA also set up a high resolution monitor to gather real-time measurements of hydrogen sulfide (H_2S) in the outdoor air near Venice, Louisiana. Monitoring detected four sources of primary air pollutants attributable to the DWH spill: (1) hydrocarbons (HCs) evaporating from the oil; (2) smoke from ISB; (3) combustion products from the flaring of recovered natural gas, and (4) ship emissions from the recovery and cleanup operations. Also examined, in addition to these primary emissions, was the subsequent production of ozone and secondary organic aerosols (Middlebrook, 2012).

Air monitoring data indicated that leaking oil and natural gas at the DWH spill site and the associated recovery and cleanup operations led to emissions of pollutants into the atmosphere. The HCs evaporating from the oil slick were the largest source of primary air emissions. Once in the air, these HCs produced the secondary organic aerosols (SOAs) and other gaseous pollutants such as ozone, nitric acid (formed from nitrogen oxides emitted from natural gas flaring and ship operations close to the spill site), and other oxidation products. Large concentrations of PAHs were not found in the SOAs. The emission factors for nitrous oxides (NO_x), CO, and soot from ISB, flaring, and ship emissions were similar to those reported from previous studies. The soot particles from the burns were confined to narrow plumes, so the absolute concentrations of particles from the burns were much higher in the plume area. Heat associated with the burning, however, lofted some of the soot particles above the marine boundary layer, where they could be transported farther away (Middlebrook, 2010).

While ISB presents a series of health concerns, it should be noted that not burning an oil spill also introduces its own air quality concerns. Analysis of the physical behavior of spilled oil has shown that 50 percent of a light crude oil spill can evaporate fairly readily and that it is the acutely toxic lighter fractions of a crude oil mix that quickly move into the atmosphere (Shigenaka, 1993). Such light-end fractions include benzene, toluene, ethylbenzene, and xylene (BTEX). All of these chemicals are known to cause liver toxicity in humans, and benzene is a human carcinogen and teratogen (Berliner, 1994). The high temperatures associated with ISB destroy the ring-structure of these chemicals and significantly reduce their air emissions (Fingas et al., 1994).

Wildlife
Though the effects of smoke on many marine animals are not fully known, it is unlikely to be worse than those caused by oil remaining as a slick on the water surface (Ames, 1994). Pelicans, for example, are notorious for diving into oil slicks (veterinarians believe the spill is mistaken for a school of fish). Sea otters and fur seals are especially vulnerable to oil, both through physical contact, which causes loss of the air-infused insulation of their fur (resulting in hypothermia), or mucus membrane irritation from the oil volatiles. Results from the NOBE test showed negligible impact of smoke on selected wildlife species (Fingas et al., 1994). Overall indications from these burn trials were that emissions from ISB are low relative to other sources of emissions and result in acceptable concentrations of air contaminants (Fingas et al., 1994).

During the DWH spill, wildlife monitors were on board vessels involved in ISB and assured no sea turtles, marine mammals, or birds were visible within the area to be burned. There were no observed impacts of the DWH ISB on seabirds or other marine wildlife.

For any ISB on California offshore waters or on land, the appropriate trustee agencies would be consulted regarding fish, birds, and other wildlife likely to be in the burn area at the time of the intended burning operations. Wildlife observers would be provided on platforms (aerial or vessel) involved in the ISB operation to assist in implementing wildlife avoidance measures and to document any wildlife seen near or entering the area during burning operations.

Surface Microlayer: Temperature and Toxicology
The surface of the water and the area immediately below it (the surface microlayer) is habitat for many sensitive life stages of marine organisms, including eggs and larval stages of fish, crustaceans, and reproductive stages of other plants and animals.

The surface area on the water affected by ISB is likely to be small relative to the total surface area and the depth of the underlying water. However, this does not necessarily preclude adverse ecological impacts that might occur with the technique, particularly for rare or sensitive species that use the waters in question. These considerations must be weighed against the impacts that would result from natural dispersion of the oil into the water column or allowing the slick to remain on the water surface.

Burning oil on the surface of the water could adversely affect those organisms at or near the interface between oil and water through elevated temperature impacts, although the size of the area affected would presumably be relatively small (Shigenaka, 1993). Observations during large-scale burns using towed containment boom (Evans et al., 1990) did not give any indication of such an impact on the waters. Water temperature tests were conducted underneath the burn site during the NOBE study and no detectable increase in water temperature was noted (Fingas et al., 1994). It has been suggested that because ambient temperature seawater is continually supplied below the oil layer during ISB, the residence time of the burning layer over the water surface may be too brief to induce a significant water temperature increase (Fingas, et al., 1994). Finally, it is important to keep in mind that oil floating on the water surface is itself highly toxic to surface microlayer organisms.

Burn Residues

Beyond the direct impacts of high temperature, the by-products of ISB may be of toxicological significance (Shigenaka, 1993). Hydrocarbons will be present in the environment regardless of whether or not the oil is burned. Although analysis of water samples collected from the upper 20 cm of the water column immediately following a burn of crude oil yielded relatively low concentrations of total petroleum hydrocarbons (1.5 parts per million), compounds that have low water solubility or that associate with floatable particulate material tend to concentrate at the air-water interface (U.S. EPA, 1986).

Serious pathologies like tumors have generally been associated with longer-term (chronic) exposures to hydrocarbons. Exposures attributable to ISB would likely be much shorter term and may not result in toxicologically significant exposures (Shigenaka, 1993), nor would they be worse than exposure to the crude oil alone. When water samples under the NOBE burns were analyzed, no compounds of concern could be found at the detection level of the methods employed. Toxicity tests performed on this water did not show any adverse effect (Fingas et al., 1994).

From an ecological perspective, there may be cause for concern that burn residue could sink due to increased oil density, as those residues could also affect benthic resources of an area that would not otherwise be significantly impacted by a spill at the water surface. Burn residues could also be ingested by fish, birds, mammals, and other organisms, and may be a potential source of fouling of fish gills, feathers, fur, or baleen. Floating or sinking burn residue could impact organisms that use surface and upper layers of the water column or benthic habitats. As impacts can also result from mechanical response actions, all potential response options should be included in an overall assessment of potential effects, and subsequent response strategies chosen that present the best response option(s) for the spill situation.

OPERATIONAL CONSIDERATIONS

Although ISB is a relatively simple technique, various factors will influence its successful use, including oil thickness, degree of emulsification, and degree of weathering. These factors generally change over time, and such changes make burning more difficult. Consequently, ISB is most easily and effectively implemented during the early stages of a spill.

Ignition

If ISB is to be used as a response method, the spilled oil must be ignited safely and effectively. Several methods have been used to ignite oil slicks, including pyrotechnic igniters, laser ignition systems, and aerial ignition systems. Pyrotechnic devices have been successfully used to ignite floating oil slicks under a range of environmental conditions. Disadvantages to their use are associated with safety, shelf life, availability, speed of deployment, and cost (Spiltec, 1987). Laser ignition remains experimental because of drawbacks associated with difficulties in beam-focusing from the air, wind effects during oil preheating, and energy requirements. Aerial ignition using gelled gasoline dropped from helicopters (a helitorch system) appears to be a more viable technique applicable in a range of environmental conditions. A helitorch was used during the NOBE open-water test burns, while hand-held igniters were used for DWH.

Physical Factors

Studies of the physical processes driving the combustion of oil on water have indicated that it is not the liquid oil that burns but rather the heated vapors above the slick (Shigenaka, 1993). Before a portion of the oil can be burned, it must be physically contained into a sufficiently thick layer. According to Buist (1987), an oil slick will continue to burn until its thickness reaches some threshold, below which the heat loss to the water is great enough to quench the fire. This threshold thickness has been reported to range between 0.8 mm (Buist, 1987) and 3 mm (Tennyson, 1991; Tebeau, 1994). Controlling the thickness of an oil slick also provides a simple means of controlling a burn (thickening it for optimal burning, or quickly quenching it for emergency suppression).

Oil weathering decreases ignitability and combustibility of oil. Hossain and Mackay (1981) found that weathering resulted in loss of volatile compounds, more difficult ignition, slower combustion, and surprisingly (in some cases), a higher proportion of oil burned. Weathering up to about 20 percent appeared to not affect the burn efficiency of crude oil. Weathering of between 20 and 35 percent of the oil increased the burn efficiency, beyond which efficiency declined.

Burning of water-oil emulsions was found to be possible with mixtures of up to 20-30 percent water. As water-in-oil emulsions approach 50%, the spill becomes difficult to ignite and may be impossible at 50-70% (Tebeau, 1994). During the DWH ISB, it was found that emulsified oil would burn if it was “fed into” an already active burn (Allen, 2011).

Generally, specialized fire boom is used for containment of oil for burning; it resists burning while the bounded oil is getting burned off. As discussed in the previous section on herders, considerable work is currently underway in the Arctic that explores the use of herders to limit oil spreading and thicken the oil to support ISB. This would reduce the reliance for delivery of specialized fire boom to the spill site before ISB can occur. This research may eventually offer more timely and effective ISB response for California as well, particularly for more spills in distant offshore waters.

Availability of Fire Boom

A past lack of fire boom available in or deliverable to California within 24 hours of a spill is no longer an issue (at least with nearshore areas), as the Marine Spill Response Corporation (MSRC) has added 1000’ of fire boom (two 500’ sections) to their inventory in Long Beach, CA. There is additional fire boom located in Everett, WA, 24 hours away, as well as at various other staging areas around the country.

The Clean Seas OSRO, based in Carpinteria, CA, responds to spills from offshore platforms and it does not currently have fire boom within their response inventory. Based on previous crude oil testing (McCourt, 2001), most of the platform oils may be unburnable. The Bureau of Safety and Environmental Enforcement (BSEE) is in the process of evaluating whether Clean Seas has a regulatory responsibility to maintain fire boom. Additional burn tests of platform crude oils are being conducted to resolve this question.

HUMAN HEALTH AND WORKER SAFETY

Personnel Safety During Ignition and Burn Phases

The burning of large amounts of combustible liquids on the surface of the water presents some unique safety concerns for workers (Shigenaka, 1993). In the *Exxon Valdez* spill, the size of the area with burning oil was easily controlled by adjusting the speed of the towing vessels (Allen, 1990). At the peak of the burning, when flames extended 45 to 60 meters into the air, and the distance from the stern of each towing vessel was about 200 meters, heat from the fire was noticeable but not uncomfortable or dangerous. The practices used during the extensive ISB during DWH (Allen, 2011) were shaped by previous experience, and led to well-controlled burning that did not pose safety risks to personnel.

Soot Reduction

Evans (1991) noted that the addition of water to oil resulted in less smoke produced during a burn and decreased the production of PAHs by up to one half. The addition of a compound called ferrocene may also markedly reduce the amount of smoke produced in the combustion of crude oil (Mitchell, 1990). Although the mechanism is not entirely understood, it is thought that the presence of iron in the combustion products causes the carbon which would otherwise form the basis for soot and smoke to be converted back into a gas phase in the form of carbon monoxide. Researchers found that the addition of relatively small amounts of ferrocene (2-4 percent by weight) to crude oil resulted in a 71 to 94 percent reduction in soot (Moir et al., 1993).

Ferrocene and its alkyl derivatives are considered to be relatively nontoxic and, though preliminary studies have been conducted in mice and dogs, additional studies would need to be conducted before use on an actual spill. Finally, another combustion product potentially found in the soot is particulate iron oxide (rust). Long-term exposure to air contaminated with iron oxide is considered to present a respirable dust hazard with no long-term health effects. For ISB, neither the concentration nor time of exposure is considered sufficient to justify a health concern (Moir et al., 1993).

GOVERNMENT AUTHORIZATIONS

The FOSC currently has the authority (via RRT IX Pre-Authorization or RRT IX Incident-Specific Authorization) to use ISB as an oil spill response tool. The process is similar to that for authorization to use a dispersant or other OSCA.

The EPA's finalized revisions to Subpart J of the NCP Product Schedule may affect how future ISB use decisions are handled. Revised Subpart J requirements may stipulate that RRT authorization is not needed even if an accelerant is used, providing all of the accelerant is consumed as part of burning. Accelerants would not then be listed on the NCP Product Schedule. Updates to the RRT IX ISB Plan will occur after the EPA NCP Subpart J revisions are finalized, and modeled on materials produced through the American Petroleum Institute (API) following the DWH experience.

Marine On-Water

The most recent finalized RRT IX ISB Plan (2005) provides for the use of ISB for oil discharges on waters within the jurisdiction of the RRT-IX California Mainland and for 35-200 nautical miles off the coast. Waters inshore of 35 nautical miles would require the FOSC to seek and receive Incident-Specific RRT IX authorization before burning could commence. Air District "Quick Approval" Zones have been established for marine nearshore areas, if winds are blowing offshore or parallel to shore during the burn operation.

Inland (Marsh, Upland)

ISB proposed for oil spilled into a water-inundated or water-proximate vegetated area in the marine zone (e.g., marsh, wetland, dunes, river mouths), where the USCG is the FOSC, would require Incident-Specific Authorization from the RRT IX and separate approval from the OSPR Administrator. Outside of the marine zone, the EPA rather than the USCG would typically provide the FOSC for the response. Clear communications with the local affected Air District would also be required to address their concerns over air quality attainment thresholds (and whether or not an EPA emergency exemption or an Air District emergency variance is required to serve in lieu of a standing EPA exemption letter). At the state level, Health and Safety Code 41801(g) allows the OSPR Administrator to authorize ISB for remediation of an oil spill, without needing an Air District permit.

ISB proposed for dry land that will not affect state waters may not require OSPR Administrator approval, but the CDFW may want assurances from OSPR that the ISB will not pose "other deleterious effects" to state trustee resources per California Fish and Game Code §5650. The EPA would need to issue override approvals or waivers to the affected Air District before a burn could proceed.

SECTION IV. FINDINGS AND RECOMMENDATIONS

OSPR'S findings and recommendations below address whether past and future ART planning supports the OSPR BAT goals. These findings and recommendations have been reviewed by outside parties, and all comments of those parties have been considered.

DISPERSANTS

OSPR achieves BAT regarding dispersant use through:

- Facilitating and monitoring dispersant research since the early 1990s;
- Remaining at the forefront of California NEBA dispersant risk analyses;
- Working with the federal trustee agencies (NMFS, USFWS) in discussing and integrating suggested BMPs for inclusion in the RRT IX DUP;
- Providing the ART Lead TS in frequent drills of the DUP;
- Participating in all ACs and serving as the lead state agency in California spill response planning, drills, and response and co-chairs the RRT's ART Committee;
- Continuing as the primary agency responsible for drafting update materials for the RRT IX DUP for California;
- Participating in on-going dispersant workshops and other response technology work groups;
- Using a biennial OSPR-Industry sponsored Response Technology Workshop to identify and present new developments in the field; and
- Delivering outreach and training on the DUP.

Applied Research

Promising areas of dispersant research and technology include:

- Continued research (begun by Kemp, 2013; Lochhead, 2015) into a lecithin-based dispersant that turns a thick oil slick into in a thin, floating, non-sticky dispersing oil mass;
- Continued research and wave tank testing of the use of high-pressure water to disperse oil (Sorstrom, S.E., 2017);
- Research into chemical dispersant formulations that do not have solvents, or solvent actions, that when used at recommended dosage may interfere with the enzymatic ability of microbes to biodegrade the oil micro-droplets formed after an effective use of dispersants;
- ExxonMobil work on development of a gel-based matrix for Corexit dispersant, which would give it a longer retention time on the oil slick;
- Research comparing the relative toxicity to wildlife of chemical dispersants versus common detergents, including those used for cleaning oiled wildlife; and
- New dispersant application technology: (1) the Neat-Sweep for more targeted application of dispersants and (2) OSRO acquisition of dispersant spray arms that mount to vessels for more targeted application from small boats.

Planning and Policy
OSPR concludes that many of the science-based assumptions used leading up to the 2008 RRT IX DUP remain valid. However, based on information gained from the DWH response, changes will be suggested for the updated RRT IX DUP for California, including:

- New Job Aids will include more operational templates and an ART Task Book;
- Subsea use, or surface use of dispersants for more than 4 days, will require "RRT IX Incident-Specific Authorization", regardless of the zone in which dispersant actions are being considered; and
- The Decision Flowchart will address baseline criteria for dispersant use, incorporate BMPs for wildlife avoidance into the FOSC and RRT IX decision processes, suggest early outreach to stakeholders, and provide additional coordination between the Planning and Operations Sections to assure all recommended or required BMPs are implemented and monitoring teams are appropriately deployed.

OSPR's past decades of dispersant research, NEBA risk analyses, dispersant use planning and job aid development, the unique state licensing program for OSCAs, and continued knowledge of dispersant research and policy development occurring nationwide sets CDFW-OSPR apart from any other state in applying BAT to provide Best Achievable Protection of the environment.

SORBENTS

OSPR meets BAT goals for sorbents primarily through evaluating sorbents for toxicity (sorbent leachates are used in the red abalone larvae test); for their ability to meet State Ocean Plan thresholds for pH, flash point, and trace metals; and whether their use would provide any "other deleterious effects" per California Fish and Game Code §5650.

Applied Research
There are enough types of sorbent products with current state licenses or exemptions from OSPR, and exempted from listing on the NCP Product Schedule, to meet the demands of current allowed uses, although applications for licensing or exemption review continue to be received and processed.

Planning and Policy
OSPR recommends increasing the range of OSPR licensed or exempted sorbent technologies considered for use during response, even those products not currently held in OSRO inventories. These products or product uses could include the following:

- Configurations using sorbent pillows along the water surface or suspended in the upper water column, to capture oil slicks, sheens, and physically dispersed oil. These can be particularly helpful on slow water spill environments (marsh, wetland, mudflats);

- Using extruded foam or other sorbent materials within the oil production and fracking industries for treatment of produced water before re-injection, or to treat spills of production water (these sorbents are often good at capturing the trace metals and other contaminants, besides oil, found in production waters);
- Use of sorbent products as buried secondary capture systems (boom, curtain, or vaults) within stream beds (including dry creek beds) for subsurface oil capture and filtering;
- Use of sorbent pads or pillows to line towed nets and for capture of subsurface (physically or chemically) dispersed oil;
- Use of loose cellulose-based sorbents (e.g., peat, coconut husk) to sorb oil on intertidal rocks before other hand cleaning;
- Use of loose cellulose-based pH neutral and seed-free sorbents (e.g., coconut husk, kenaf, bagasse), blown onto the stems of oiled vegetation in marsh/wetland habitats, to reduce the "contact stickiness" of oil to birds and marsh wildlife; and
- Use of loose cellulose-based pH neutral and seed-free sorbents (e.g., coconut husk, kenaf, bagasse) as a binder and bulking agent for liquid bioremediants used in land-based/land-farming bioremediation projects.

Efforts should also focus on use of sorbent products that can reduce the amounts of generated waste. This would include focused attention on use of reusable sorbents and of sorbent products that can be converted to other uses when soiled (fuel, road base materials), rather than landfill disposal.

SURFACE WASHING AGENTS

OSPR meets BAT goals for Surface Washing Agents through:

- Only issuing OSCA licenses for surface washing agents categorized as "lift-and-float" so that oil washed from hard surfaces or sediments into the water can be recovered; and
- Continuing to facilitate appropriate authorizations for use of surface washing agents during spill responses and/or actively supporting pilot testing during responses.

Applied Research

OSPR supports the additional testing the EPA is conducting on the effectiveness of surface washing agents. Additional research is needed into the possible uses of surface washing agents in inland spill response settings (e.g., for flooding of oiled dry creek bed sediments and capture of re-floated oil).

OSPR encourages additional investigations into the possible use of truck-based systems, use of roll-off bins, or construction of temporary sand-cleaning facilities as a means to promote future site-based sand cleaning. This approach was effectively used during the DWH spill and has value in California spill response as it would allow cleaning and replacement of native sand, rather than excavation and off-site disposal of oiled sand.

Planning and Policy

OSPR will work with the RRT IX to identify their authorization responsibilities when surface washing agents are used in an *ex-situ* manner (no runoff to water) versus *in-situ* (when there is likely or potential runoff to water). OSPR also recommends working with RRT IX to investigate whether there are any likely circumstances in California marine or inland uses of a surface washing agent where pre-authorization could provide additional and timelier response value.

SOLIDIFYING AGENTS

OSPR meets BAT goals for solidifying agents through:

- Only issuing OSCA licenses for solidifiers or other elasticity modifiers that can be used in a proper form. For example, liquid gelling agents can only be used in a spill response context where the oil + gel matrix cannot escape to water or be unrecoverable if it escapes (these restrictions lead to a low likelihood of use); and

- Continuing to facilitate appropriate authorizations for use of solidifying agents during spill responses and/or actively supported pilot testing during responses.

Applied Research

The following are potential projects exploring novel uses of solidifiers. Results from these studies could help the response community better meet our collective BAT goals:

- Further research into whether liquid gelling agents, or loose particulate forms of solidifiers, could be used as a self-creating barrier to bound surface oil slicks;
- Further research into the use of loose/broadcast particulate solidifiers on gravel beaches where deep oil penetration is of great concern; and
- Further investigations of whether oil + loose particulate can be recovered by mechanical skimmers or whether recovery of a mat of solidified oiled can only be done by hand (e.g., raking).

Planning and Policy

Use of solidifiers in self-contained form may provide advantages over the use of conventional sorbent products and should be further considered for use in near-shore marine and inland spill response environments. Solidifiers also may have promise with respect to stopping vessel or pipeline leaks. OSPR supports the expanded use of OSPR licensed self-contained solidifier technologies to take full advantage of available technologies during spills.

As with many of the sorbent products, broader use of the more effective self-contained solidifiers could include the following:

- Configurations using particulate solidifier pillows, along the water surface or suspended in the upper water column, to capture oil slicks, sheens, and physically dispersed oil. These can be particularly helpful on slow water spill environments (e.g., marsh, wetland, mudflats) where capture of re-sheening oil can be maximized;
- Use of solidifying materials within the oil production and fracking industries for treatment of production water before re-injection or to treat spills of produced water (these solidifiers are often good at capturing the trace metals and other contaminants, besides oil, found in production waters);
- Use of self-contained solidifier products as buried secondary capture systems (boom, curtain, or vaults) within stream beds (including dry creek beds) for subsurface oil capture and filtering; and
- Use of solidifier pads or pillows to line towed nets and for capture of subsurface (physically or chemically) dispersed oil.

Efforts should also focus on use of self-contained solidifier products that can reduce the amounts of generated waste. This would include focused attention on use of reusable self-contained solidifier products that can be converted to other uses when soiled (fuel, road base materials), rather than landfill disposal.

OSPR also supports further consideration of using loose particulate solidifiers, within a containment-boomed area, for treatment of spills near wetlands and on ponds and lakes, and potentially in marinas and harbors.

HERDING AGENTS AND DE-EMULSIFIERS

Applied Research

OSPR will continue to follow any advancement in the use of herding and de-emulsifying technology. Research underway by ExxonMobil indicate that positive effects of herding agents are short-lived and subject to disruption by advanced sea states. BSEE has several wave tank studies planned that will further investigate the properties and efficiencies of herders under a variety of test conditions. OSPR may also in the future support studies of use of herders + barrier boom + sorbent to treat spills of diesel and fuel oils in marinas and harbors.

Planning and Policy

While OSPR does not currently license any herding agents or de-emulsifiers, these products have potential to support use of dispersants and/or ISB during spill response. There are processes within both the RRT IX RCP and OSPR licensing regulations that allow consideration of an as yet unlicensed OSCA such as a herding agent or de-emulsifier, on a case-by-case basis.

BIOREMEDIANTS

OSPR meets BAT goals for bioremediation through continuing to facilitate evaluations for use during spill responses and/or actively supporting pilot testing during responses.

Applied Research

OSPR supports the research recently funded by the Oil Spill Research Initiative (OSRI) to do a components analysis of one bioremediant product (OSEII) that the manufacturer claims can be used in on-water and shoreline applications. While on-water bioremediation technology does not currently present a feasible option to conventional cleanup technology, the OSRI-funded research will help determine whether this technology will evolve into a significant response tool.

Planning and Policy

OSPR supports the EPA's proposed revisions to the NCP Product Schedule Subpart J, requiring both efficacy and toxicity tests (with established thresholds) for bioremediants. This will be useful information for the state, as it will directly apply to the state's revised OSCA licensing regulations and guidance.

IN-SITU BURN

OSPR meets BAT goals for ISB through:

- Working with the RRT IX in development and updates to the RRT IX ISB Plan;
- Assisting the RRT IX in determining the boundaries and/or continuing need for an ISB Pre-Authorization Zone;
- Working with coastal Air Districts in the development of offshore Quick Approval Zones; and
- Being state lead on all oil spill drills that exercise ISB, often negotiating with local Air Districts and the U.S. EPA on what is required for Air District concurrence with the emergency burning of oil.

Research

OSPR continues to follow national and international research being conducted by other agencies and institutions, in particular tracking research that further explores the formation of nitrated PAHs and whether they would be a human health or environmental concern during ISB in California. OSPR also supports the BSEE in any future tests regarding the potential for burning California crude oils and is tracking research into the use of de-emulsifiers to prolong an ISB window of opportunity. OSPR also supports additional studies of methods to stabilize oil slicks and increase the heat of ISB, which may result in lower soot volumes and/or burn residues.

Planning and Policy

The following recommendations are based on updates to the RRT IX ISB Plan:

- Based on finalized revisions to the EPA's Subpart J, determine the respective authorities of the RRT IX and the OSPR Administrator to approve offshore and inland/upland burns;
- Determine whether ISB will be considered a mechanical approach, rather than an ART, and determine if there is still a need or basis for an offshore Pre-Authorization Zone for ISB;
- If an offshore Pre-Authorization Zone is retained, the RRT IX should reconsider the boundaries to accommodate a better understanding of what offshore species might be present and potentially affected (e.g., consider a Pre-Authorization Zone boundary just seaward of the Continental Shelf, as numbers and diversity of species diminish seaward of the Shelf);
- Re-visit the Air District offshore marine Quick Approval Zones, and determine if there should be additional offshore "buffers";
- Memorialize and include (perhaps as an MOU with the California Air Resources Board) clarifications of federal and state override provisions already in regulation regarding emergency ISB;
- Include in the updated RRT IX ISB Plan an EPA waiver letter for Air District reference. This letter should clarify that EPA will waive an affected Air District's ambient air quality attainment thresholds in cases where there is a federal- and state-authorized burn. The waiver should clearly acknowledge that Air District Open Burn rules do not apply during federal- or state-ordered emergency ISB operations. If ISB is requested by the FOSC and approved by the EPA, exceedance of ambient air thresholds will not result in an Air District violation; and
- Include Job Aids in the updated RRT IX ISB Plan that provide relevant contacts as well as operational templates for air monitoring, wildlife monitoring, operational practices to minimize environmental impacts, and public outreach, media messaging, and risk communication tools.

SECTION V. LIST OF ACRONYMS

AC	Area Committee
ART	Applied Response Technology
ATSDR	Agency for Toxic Substances and Disease Registry
BAT	Best Achievable Technology
BMP	Best Management Practice
BP	British Petroleum
BSEE	Bureau of Safety and Environmental Enforcement
BTEX	Benzene/Toluene/Ethylbenzene/Xylene
CAFÉ	Chemical Aquatic Fate and Effects
CARB	California Air Resources Board
CDFW	California Department of Fish and Wildlife
CFR	Code of Federal Regulations
CO	Carbon Monoxide
COOGER	Centre for Offshore Oil Gas and Energy Research
CROSERF	Chemical Response to Oil Spills Environmental Research Forum
DFO	Department of Fisheries and Oceans Canada
DOMP	Dispersed Oil Monitoring Plan
DOSS	Dioctyl sodium sulfosuccinate
DUP	Dispersant Use Plan
DWH	*Deepwater Horizon*
e.g.	Abbreviated form of *exempli gratia,* Latin for “for example”
EPA	Environmental Protection Agency (may also be noted as USEPA)
ESA	Endangered Species Act
et al.	Abbreviated form of *et alia*, Latin for "and others."
FDA	Food and Drug Administration
FOSC	Federal On-Scene Coordinator
GOM	Gulf of Mexico
HC	Hydrocarbons
i.e.	Abbreviated form of *id est*, Latin for “in other words”
ISB	*In-situ* Burning
LC	Lethal Concentration
LISST	Laser *In-situ* Scattering and Transmissometer
LSC	Louisiana Sweet Crude
MMS	Minerals Management Service
MSRC	Marine Spill Response Corporation
NCP	National Contingency Plan
NEBA	Net Environmental Benefit Analysis
NMFS	National Marine Fisheries Service
NO	Nitrous Oxide
NOAA	National Oceanic and Atmospheric Administration
NOBE	Newfoundland Off-shore Burn Experiment
NRC	National Research Council
OPA/OPA90	Oil Pollution Act of 1990
OSCA	Oil Spill Cleanup Agent

OSPR	Office of Spill Prevention and Response
OSRO	Oil Spill Response Organization
PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Material
ppb	Parts per billion
ppm	Parts per million
RCP	Regional Contingency Plan
RRT	Regional Response Team
SMART	Special Monitoring of Applied Response Technologies
SOA	Secondary organic aerosols
SSC	Scientific Support Coordinator
TPH	Total Petroleum Hydrocarbon
TPAH	Total Polycyclic Aromatic Hydrocarbon
TS	Technical Specialist
UC	Unified Command
USCG	United States Coast Guard
USFWS	US Fish and Wildlife Service

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