Considerations for the Application of Controlled In-Situ Burning

Neré J. Mabile, BP America

Summary
The burning of oil in place (in situ) on water is a viable means of mitigating the impact of marine oil spills. This paper defines three phases of decision-making, prioritizes the key issues of each phase, and proposes a process for analyzing the issues when considering controlled in-situ burning as an early response option in both icy and warm conditions. Also provided is a fact-based consideration of safe practices, such as those involving potential personnel exposure, sealife exposure, ignition control, fire control, and vessel safety. Controlled in-situ burning (ISB) can be initiated on a pre-approved or case-by-case basis, and there is generally a short operational time window during which it can be effectively used; therefore, quick, informed decision-making is imperative. This paper provides a discussion of these factors, along with a knowledge base of best practices that includes general categories of considerations, decision-making support tools, and specific operational approaches. The Deepwater Horizon response is used to illustrate both the operational approaches and the three decision-making phases; however, every situation is different and calls for decisions based on the individual circumstances. Because of its long history of research, testing, and use during spills, as well as positive environmental tradeoffs, controlled ISB is now considered by many to be a conventional response option.

Introduction
On a number of occasions over the last 50 years, controlled in-situ burning has been used to remove oil spilled on water (Fingas 1999). Today, because of decades of research and testing, controlled ISB has an immense knowledge base and an impressive success rate. According to the US Coast Guard (USCG), the National Oceanic and Atmospheric Administration (NOAA), and the US Environmental Protection Agency (EPA), controlled burning removed between 220,000 and 310,000 bbl of oil from the Gulf of Mexico during the response to the Deepwater Horizon (DWH) spill in 2010 (Schaum et al. 2010; Aurell and Gullett 2010; Lubchenco et al. 2010; Allen et al. 2011). However, experts in controlled ISB have noted that the paradoxical nature of igniting a fire as a response tactic and the emissions produced by the burning oil have been hurdles for the response community to overcome in terms of public perception. In reality, fire can easily be controlled, and using it to remove spilled oil from the offshore environment has more pros than cons. For instance, according to numerous tests involving controlled ISB, the residue produced by a controlled ISB is far less toxic than the spilled oil and is approximately 1 to 10% of the original volume if optimal burning thicknesses can be reached through the use of fire-boom containment or chemical herders (McCourt et al. 1999; Walker et al. 2003; Buist et al. 2003; Michel et al. 2005; Potter et al. 2012; ASTM 2002). The time has come for the value of controlled ISB to be recognized and for it to be fully understood by the worldwide response community.

Since the Newfoundland Offshore Burn Experiment in the mid-1990s, which clearly demonstrated the effectiveness of controlled ISB, the acceptance of controlled ISB as a conventional oil spill countermeasure has grown (Fingas 1997). NOAA recently stated that "ISB technology and use has resulted in a general trend by US decision-makers for a growing acceptance of this option as a standard countermeasure for larger, offshore spills and certain inland, on-water spills in isolated locations" (2003). Certainly, after proving itself to be safe and effective for decades and then providing almost 3 months of successful application on an unprecedented scale, controlled ISB is now considered by many to be a conventional, rather than an alternative, response option.

With careful consideration, the most environmentally beneficial solution to an oil spill can be determined, and any risk of exposure can be minimized. The greater the number of response options and the better these options are understood, the greater the degree of success that can be achieved during a response. A full understanding of controlled ISB requires a study of the general spill conditions, feasibility issues, and site-safety considerations that affect decision-making. This discussion of controlled ISB parameters is presented with the assumption that the required resources (personnel and equipment) can be assembled at the spill site in the required timeframe. Before committing to a controlled ISB, decision-makers have several phases of assessment to complete.

The Three Phases of Decision-Making
Several key issues must be analyzed to determine the appropriateness of using the controlled ISB option on water. The considerations can be divided into three distinct phases of decision-making:

- The first phase addresses general safety and overall burn feasibility and applicability at the beginning of a response.
- The second phase addresses the ability to ignite the oil in existing conditions during each operational period.
- The third phase involves specific safety considerations at the burn location before igniting each burn.

The priority first-phase issues include the distance from populated areas, the type of spill (continuous or batch) and/or the amount of time between the spill and the beginning of controlled ISB operations, the capability of mechanical recovery to remove the oil sufficiently, regional regulations, the migration scenario, and the type of hydrocarbon spilled.

Note: If the spill is subsea, continuous, and more than 3 nautical miles from populated areas, as in the case of the DWH spill, then ISB is likely to be a significant contributor to the response effort, and its use should be placed on the "decision table" as soon as practical.

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After the decision has been made to use controlled ISB as a response option, the second phase of decision-making begins. These considerations involve the more temporal and transient conditions, such as the thickness of individual slicks, weather and wave conditions, and emulsification. Decision-makers must be armed with a knowledge base that delineates not only the issues that must be considered, but how these issues are influenced by other factors and by each other. A simple decision matrix that includes all factors is not plausible.

Upon arriving at the site of a planned burn, the ISB on-site leader completes the third phase of decision-making, which comprises the site-safety conditions at the time of a burn. These considerations involve on-water operations and include the potential for personnel and sealife exposure, the ability to control the ignition and ensuing fire, and general vessel safety, particularly during simultaneous operations.

Prioritizing the Phase I Issues. The Incident Commander, or Federal On-Scene Coordinator (FOSC), typically addresses the Phase I issues at the beginning of a response. Proximity to populated areas is often considered the most important issue when weighing the pros and cons of conducting a controlled burn; however, current guidelines and regulations do not all agree on the minimum-allowable distance, and wind direction is also a major factor in determining an acceptable distance. Most guidelines require a distance of 3 nautical miles, but others recommend a minimum of 0.5 to 1 nautical mile, depending on wind direction (RRT VI 1994; ARPEL and Fingas 2006; Fingas and Punt 2000; Buist et al. 2003). Most of the key issues have similar analysis requirements based on actual conditions at the spill site. To rank the importance of each of these issues, one must first realize that each is partially dependent upon the location and the time of year. For instance, weathering effects on spilled oil occur more slowly in icy conditions than in warm water, and mechanical recovery equipment is less likely to be able to reach an arctic or subarctic spill location during winter and early spring ice buildup and breakup conditions (ASTM 2002; Alaska Clean Seas 2008; Fingas 2004; Bernhardt and Hart 1995, Buist 2004; Buist et al. 1987; Velez et al. 2011; Potter et al. 2012). Perhaps the best way to prioritize the Phase I issues is to first categorize the response conditions as icy or non-icy.

The following first-phase issues, not necessarily listed according to importance, must be considered before authorizing the use of controlled ISB in response to a spill:

- Type of spill (batch vs. continuous) and/or amount of time that has passed since the spill
- Proximity to populated areas
- Regional guidelines and regulations
- Migration of the oil/ice
- Capability of mechanical recovery methods to adequately remove the spilled oil
- Type of hydrocarbon spilled (similar issues in both icy and non-icy conditions)

In the following subsections, these considerations are analyzed based on icy and non-icy conditions, which tend to affect the acceptable parameters.

Icy Conditions. For arctic and subarctic climates, the ISB response window is typically much wider, so time is less of a factor in decision-making. In other words, the type of spill (continuous vs. batch) is not as critical. However, the thickness, prevalence, and movement of the ice can be critical issues, depending on the season, in considering whether or not and, if so, when to conduct a controlled burn. The thicker the ice, the harder it will be to conduct mechanical recovery operations, but the more likely the oil is to stay in place. According to the 2012 report prepared for the American Petroleum Institute (API), "In 70% to 90%+ ice cover, the closely packed floes will effectively contain the oil" (Potter et al. 2012; NOAA 2010). Ice concentrations of 30 to 70% will inhibit the flow of spilled oil but may not completely contain it. Late fall ice floes in a subarctic region may allow mechanical recovery vessels to reach the spill site, possibly precluding or reducing the need for controlled ISB, depending on the weather and the rate of ice-buildup in the area.

Ice also acts as a natural boom, keeping the oil in place and reducing the effects of weathering and emulsification for a much longer period of time, which is conducive to the controlled ISB option. As the ice concentration increases, movement and breaking down of the oil decreases, keeping the oil "fresh" (ASTM 2002; Alaska Clean Seas 2008; Fingas 2004; Bernhardt and Hart 1995; Buist 2004; Buist et al. 1987; Velez et al. 2011; Potter et al. 2012). After establishing a sufficient distance from populations, decision-makers can choose to burn any spilled oil that responders can access, or to wait until the spring thaw, when the oil migrates to the surface in melt pools. During the late fall, winter, and spring ice-breakup seasons, controlled ISB is often considered the best option, but there is less of a sense of urgency because the ice and snow can act as natural response aids, corralling and preserving the oil for removal at a time that is optimum from a safety perspective* (Buist et al. 1987).

Arctic regions are also sparsely populated, so a spill is less likely to occur within 3 nautical miles of a populated area. In contrast, one unusually complicated consideration in the arctic and subarctic regions tends to be the regional guidelines and regulations. Typically, indigenous populations have their own requirements and must be treated as vital stakeholders in the oil-spill response process* (United States Government Accountability Office 2010).

The 2000 IPIECA report on "Choosing Spill Response Options to Minimize Damage" asserts that ISB is the only viable option for ice-infested waters. New technologies are currently underway, however, to improve the probability of success for other options in icy conditions.

Non-Icy Conditions. For warmer climates, time is the critical factor in the first phase of decision-making, unless the spilled oil is the result of an uncontrolled blowout that continually releases oil into the environment. For continuous spills, the oil weathering, emulsification, and spreading become Phase II issues.

In the US, if the spill site is more than 3 nautical miles from populated areas, according to most regional and regulatory guidelines, and the oil cannot be removed sufficiently through the use of mechanical recovery alone, responders should be authorized to begin controlled burning operations as soon as the team and equipment can be assembled. In these cases, the spill may have occurred in a pre-approved zone, which helps to expedite the process. The approval zones are discussed in the section on controlled ISB initiation.

In a batch spill, factors such as evaporation, emulsification, and spreading thinning slicks make the burn window very narrow and, therefore, must be considered during the first phase of decision-making. As oil evaporates, it loses its "lighter" ends and becomes more difficult to ignite. The most critical issue with regard to time, however, is how much wave action energy the spilled oil has encountered and, as a result, how much emulsification has taken place. Typically, ISB ignition begins to be difficult at 25% stable, oil-in-water emulsions (Buist 2004; Alaska Clean Seas 2008; Buist et al. 2003; ExxonMobil 2008; Fingas 2004; Potter et al. 2012). In testing, demulsifier chemicals have shown some promise in extending the burn ignition window (S.L. Ross 1995), and current research and development are underway to continue improving on this innovation.

When the initial decision to burn has been made, the decision-making moves to the second phase, which includes the more transient requirements of burning on water.

Type of Hydrocarbon Spilled. The characteristics of the type of hydrocarbon spilled rarely affect the initial decision to burn, but there can be slight differences in the oil's ignitability, viscosity, and

*Personal communication with A. Allen. 2012. Houston: BP.

TABLE 1—IDEAL AND MINIMUM-REQUIRED* CONDITIONS FOR CONTROLLED ISB[††]

Consideration	Ideal Conditions	Minimum-Required Conditions
Oil thickness	> 2 mm (> 0.8 in.) for most "fresh" oils [a] ~2– 5mm for weathered crude [b]	1–3 mm (0.04–0.12 in.) for "fresh" crude oil, 3–5 mm (0.12–0.2 in.) for diesel and weathered crude, 5–10 mm (0.2–0.4 in.) for some others, depending on oil type (e.g., weathered crude, diesel—Bunker C fuel oil)
Emulsification	0–12.5% water [c]	< 25% water for crude oils that form stable emulsions [c], < 50% for light crudes that form unstable emulsions [d,e]
Weathering (evaporation and exposure)	20–35% evaporated < 48 hrs exposure in warm weather	35% evaporated, ~55 hrs exposure, depending on temperature, < 72 hrs in cold conditions, but undetermined limitations in ice [f]
Waves**	< 1 m (< 3 ft)	< 1.5 m (< 5 ft)
Wind[†]	< 2–10 m/s (3.89–19.4 knots) Some wind actually "promotes better combustion" [c]	< 10 m/s (20 knots), < 13.9 m/s (27 knots) [g], < 10–12 m/s (19.4–23.3 knots) for large burns [c], 10–12 m/s (20–25 knots) [h]
Current	< 0.75 knots, perpendicular to a boom	< 0.5 m/sec (< 1 knot)
API Gravity/density[†††]	< 0.864 gram/milliliter (g/mL)	< 1.0 g/mL [e]

* The minimum-required conditions result in reduced efficiency and success rate and may require additional burning agents, ignition methods, and/or booming techniques.

** If wave periods are longer and create more of a rolling wave, then existing containment fireboom could still accomplish burning with higher wave heights.

† In icy conditions, some wind and current can act as a herder to help collect oil into a sufficient thickness for burning.

†† ARPEL 2006; Alaska Clean Seas 2008; Buist et al. 2003; Walker et al. 2003; ExxonMobil 2008; Fingas 2004; Northwest Area Contingency Plan 1995; Potter et al. 2012; Buist 2004

††† Density increases with time and increases slightly as temperature decreases

a ASTM 2002

b Potter et al. 2012

c Buist 2004

d Fingas 2004

e Walker et al. 2003

f Alaska Clean Seas 2008

g ExxonMobil 2008

h Bech et al. 1993 from Potter et al. 2012

buoyancy. According to the US Code of Federal Regulations (CFR) and the ITOPF, hydrocarbons fall into five categories (groups) based on specific gravity and volatility (US Code of Federal Regulations 1996; ITOPF 2002). Although rare, a few Group 5 oils are heavier than seawater [specific gravity >1.025 gm/ml (less than 6°API)] and, therefore, can sink below the surface and make successful controlled ISB impossible [e.g., case study of coal tar oil spilled into the Detroit River (Helland et al. 1997)]. Certain Group 4 and 5 heavy crude oils can also become heavier than seawater when they have been subject to evaporation, have mixed with sand in the water column, or possibly have been heated but not burned (Michel 2007; Michel and Galt 1995). However, these hydrocarbons have been known to resurface (e.g., if the sand settles to the seafloor due to gravity) (Michel and Galt 1995), so a controlled ISB is still theoretically possible in some cases.

Viscosity is slightly less of a factor in icy conditions because the cold weather slows the spreading of the oil (Overstreet and Galt 1995; NOAA 2010). Current speed, regardless of the ambient temperature, is probably the most important parameter with regard to the viscosity of heavier oils. A 2009 report for the UK's Maritime and Coastguard Agency explains, "if the current speed is high and the viscosity of the oil is relatively low, the oil may be sheared into relatively small droplets and be dispersed by the currents into the water column and eventually sink over a very wide area." Conversely, if the current is slow and viscosity is also low, the heavy oils are likely to pool on the seabed (Rymell 2009).

Prioritizing the Phase II Issues. When responding to a continuous spill, the ISB Technical Advisors typically address the Phase II issues just before or at the beginning of each operational period. Once it has been determined that controlled burning is appropriate for the spill scenario, then ISB technical advisors must determine the ignitability of the oil slicks in the conditions expected for each operational period. The existing guidelines, some of which are currently being revised, do not all agree on the required, minimum, and ideal parameters. In a 2004 document titled *Weather Windows for Oil Spill Countermeasures,* Merv Fingas noted that the guidelines and estimates "vary considerably." In the case of the DWH response, however, the ignitability of the oil could be predicted and controlled, and the only factors that remained variable were the weather, wind, and waves.

The thickness of an oil slick would be the most important Phase II consideration because it has the greatest effect on ignitability; however, using fire boom to contain the oil can easily mitigate any thickness issues. A thickness of approximately 2 mm is necessary to maintain continuous combustion (ASTM 2002; Buist 2004; Alaska Clean Seas 2008; Walker et al. 2003; Buist et al. 2003; ExxonMobil 2008; Fingas 2004; Potter et al. 2012). In addition, thicker oil slicks have greater burn efficiency (Bernhardt and Hart 1995). Very light oils (e.g., diesel) have a lower viscosity and are difficult to collect into slicks of minimum thickness for ignition, and very heavy oils (e.g., Bunker C fuel), in addition to their tendency to sink, are more difficult to ignite (NRT 1992; Fingas 2004). Group 2 through 4 oils (e.g., crude oils) are ideal for the controlled ISB option (Buist et al. 2003; US Code of Federal Regulations 1996). Although the oil type is listed as a Phase I consideration, it does affect the degree to which the Phase II considerations are relevant.

Fig. 1—Evacuated Summa canisters collecting air samples to measure for BTEX VOCs along the Florida coast.

Fig. 2—Sealife spotter during the DWH response.

Note: The ambient temperature of the air and water surrounding spilled oil has not been shown to affect the ability to ignite and sustain a burn.

The following second-phase issues, not necessarily listed according to importance, must be considered before conducting a controlled ISB during each operational period:

- Oil-slick thickness
- Wind, wave, and current conditions
- Emulsification of the oil (ignitability)
- Weathering of the oil (evaporation/exposure)

Table 1 provides the minimum and ideal conditions for conducting a controlled ISB offshore.

Prioritizing the Phase III Issues. The ISB Task Force Leader, or on-site leader, typically addresses the Phase III site-safety issues immediately before igniting each controlled burn. These issues include conditions encountered at the planned burn site that might affect the possibility of personnel exposure to particulates, the ability to control the fire from the point of ignition to full burn, and the safety of multiple vessels and crews operating simultaneously in the area. Using the ICS system, each level of management for a controlled ISB operation maintains an effectively sized span of control that encompasses no more than seven entities for each leader. Therefore, each ISB on-site leader manages an Ignition Team, the captains and crews of two vessels pulling the fire boom, and the captain of a fire-control vessel. Efforts to ensure the safety of the crews and vessels are also supported by the Incident Management Team onshore [e.g., Simultaneous Operations (SIMOPS), Planning and Logistics Section analysts (meteorological and geographical), Air Quality Monitoring Specialist, and Air Operations responders].

Human Exposure. Human exposure to particulates is typically easy to prevent and depends primarily on monitoring wind direction and vessel proximity. During the DWH response operations, fire-boom-towing vessel captains easily maneuvered their crafts to avoid smoke plumes and maintained a distance of at least three "fire diameters." The crews of these vessels had received training specific to controlled ISB operations, including safety protocols and the use of personal protective equipment (PPE) (Papp 2011; NIOSH 2011). In addition, industrial hygiene specialists were used for personnel monitoring around controlled ISB operations. The vapor concentrations and potential for fire spreading were assessed immediately before each burn was ignited. Also during the DWH response, NOAA measured particulates and found that the air near the smoke plume was well within an acceptable range and that the plumes dispersed quickly. According to NOAA, the highest level of submicron particulate mass that was measured downwind of the spill was 20 μgm^{-3} on June 8, which is well below the National Ambient Air Quality Standard for particulate matter less than 2.5 µm in diameter (Middlebrook et al. 2012). Essentially, per NOAA, the overall air quality near the DWH site in the Gulf of Mexico was similar to that of a major city (NOAA website 2011). If vessels avoid positioning downwind of a controlled ISB, then the concern of potential exposure is minimized. The air quality was also monitored by government and private groups along the shoreline to detect and record any potential impacts to populated areas. For instance, the Florida Department of Environmental Protection and the US Environmental Protection Agency (EPA) monitored four sites along the Florida coast using evacuated Summa canisters **(Fig. 1)** to sample for the BTEX volatile organic compounds (VOCs) (Florida Department of Environmental Protection 2012). This testing showed no potential exposure to levels of concern.

In 2003, the US Coast Guard asserted, "In general . . . the smoke plume is not a safety threat to the public nor to the environment because it has very low toxicity and readily dissipates" (Buist et al. 2003; Walker et al. 2003).

Sealife Exposure. Controlled ISBs are not conducted in the presence of any observed wildlife. During the DWH response, trained wildlife specialists **(Fig. 2)** served as observers on the controlled ISB operations teams. Sealife observation was one of the decision points used for controlled ISB ignitions. During the response to the DWH, there were no sealife impacted by the controlled ISB operations.

Ignition Control. A critical issue in oil-on-water ignition is the amount of time the oil slick has been exposed to the environment. Through evaporation, the lighter, volatile hydrocarbons are removed from the oil, thereby making the oil more difficult to ignite.* "Fresh" oil (oil that was only recently exposed to the environment) tends to be more volatile because the "lighter ends" have not yet evaporated (McCourt et al. 1999). Another very important factor in the ability to ignite is the amount of emulsification that has taken place. The longer oil is exposed to wave energy at sea, the higher the chance it has of forming a stable emulsion. The more water emulsification there is in the oil, the harder it is to ignite the oil. Therefore, again, fresh oil is easier to ignite because lighter ends provide more vapors for combustion. During the DWH re-

*Personal communication with A. Allen. 2012. Houston: BP.

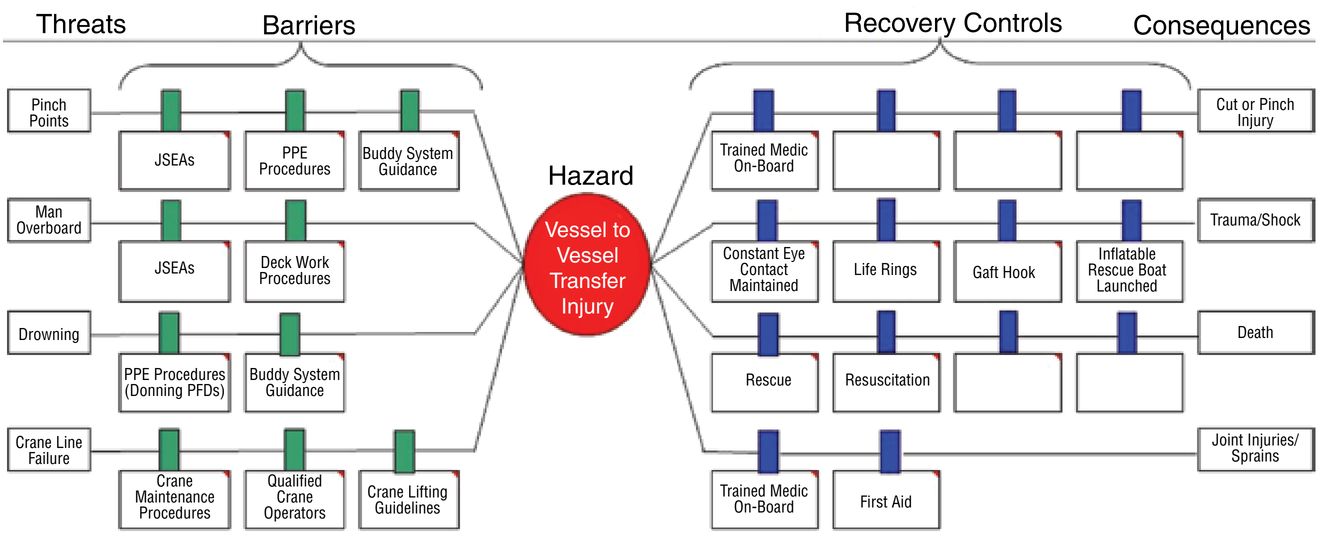

Fig. 3—"Bowtie" diagram developed during the DWH response to help prevent accidents during vessel-to-vessel transfer.

sponse, the oil was relatively fresh but it was somewhat emulsified and had time for some of the light ends to evaporate before being encountered by burn teams. The emulsification was a result of both the distance the oil had to travel from the seafloor to the water surface and the amount of wave action it encountered before being collected in fire boom. Ignition teams repeatedly measured the VOC level before approving ignition for each burn to confirm that there were no potentially explosive conditions present. There were never any problems encountered with explosive limits during the DWH response's controlled ISB operations.

Fire Control. Fire control mirrors the issue of ignition control but has two additional factors: distance and size. In order to ensure safety from the heat of the fire, responders and vessels must maintain at least three fire diameters from the controlled burn.

In the past, ISB researchers have theorized that a burn can be extinguished by "speeding up the tow so that oil is submerged under the water" (ARPEL 2006). During the DWH response, one ISB team was able to prove this theory when it became late in the operational period and responders needed to extinguish a burn. Allowing entrainment, they simply accelerated and pulled the fire boom greater than one knot to force collected oil under the boom, thereby releasing containment and successfully extinguishing the controlled burn. In addition, as a test and demonstration at the end of one burn, an ISB team used a water cannon from a supply vessel to successfully extinguish a controlled burn.

Vessel and Crew Safety. In addition to controlling the burn, the ISB on-site leader must ensure that crews have been sufficiently trained for their assignment, vessels are maintained properly, personnel are trained in vessel-to-vessel transfer **(Fig. 3),** and vessel movements are coordinated. During the DWH response, all responder-vessel crews reported to the Command vessel leaders and were required to participate in daily safety meetings to help ensure that they maintained a state of safety awareness. Vessel-to-vessel transfers were identified as the highest risk for personnel during the offshore operations activity. During daily work shifts, personnel had to routinely shuttle from the Command vessel onto smaller vessels and back again after the work activity was completed. This safety hazard was highlighted during every safety meeting held before the start of work shifts. Operations activities were also organized to minimize the need for transfers by leveling resources. Personnel were continually reminded of all identified hazards and were reminded to always use the "buddy system" to look after each other during daily activities, especially transferring to other vessels at sea.

General Risk Mitigation

As is the case with many operational endeavors, the ability to effectively mitigate risks during controlled ISB operations depends on experience and training in areas such as identifying hazards, following established protocols, using a built-in alert system, reviewing potential hazards before commencing activities during each operational period, making timely operational adjustments, reflecting on operational challenges, and documenting adjustments through management-of-change (MOC) procedures. Some level of risk exists in any activity, so perhaps an important general question for safety responders is "What level of risk is acceptable?" Once this is determined, safety personnel can begin crafting protocols and training for each specific risk, and decision-makers can use a more effective risk-based approach (Potomac Management Group 2002).

The next important question in mitigating risks is "What are the potential primary root causes of each type of risk?" For instance, injuries during vessel-to-vessel transfer typically result from failure to do the following: wear the appropriate PPE/PFD, use the buddy system, understand the protocols for operating the crane, inspect the crane lines, and so on. Therefore, addressing each of these issues is essential to mitigating the risk of injury during the transfer. The next two questions are "What can happen if responders fail to follow the protocols?" and "What can help to ensure that the protocols are followed?" In this case, an effective plan for mitigating the risk will involve training, practice, monitoring the use of protocols, and an awareness of the potential consequences for poor performance. The "bowtie" diagram shown in Fig. 3 was used to help train and raise the awareness level of DWH responders regarding vessel-to-vessel transfer. In general, visual training methods are more effective than words alone. This simple diagram proved to be very successful in impressing upon responders how their actions (barriers) could prevent an unwanted event, such as injuries. It also helped response personnel see and understand the threats and then the consequences of not paying attention to the prevention methods.

Types of Controlled ISB Initiation

Regional Response Teams (in the US), local governments, and/or regulatory agencies can approve burn zones for their region in advance and can identify areas that have the potential for approval. For instance, some areas within approximately 3 nautical miles of the US shoreline are considered exclusion zones, so controlled ISB operations are not an option. With the exception of the exclusion zones, controlled burns in the US can either be pre-approved, or can be approved on a case-by-case basis by the Incident Commander (Buist et al. 2013; RRT VI 1994; NACP 1995).

Pre-Approved Burn Zones. Some deepwater production and pipeline locations are already listed by local governments and/or regulatory agencies as pre-approved burn zones. For instance, RRT VI had already approved the use of controlled ISB at the DWH location. “The preapproval allows FOSCs to permit responsible parties to employ the plan seaward of three miles of the coasts of Louisiana and Texas, with areas excluded offshore in the vicinity of certain reefs and an area off Grand Isle, Louisiana” (RRT VI 1994). The primary basis for assigning a pre-approval status to a location is its proximity to shoreline and populations.

Case-by-Case Approvals. If an oil spill occurs fewer than 3 nautical miles from a shoreline, the applicable government or regulatory agency may assign its status as approved on a case-by-case basis. In these spill locations, an Incident Commander may be required to include regulatory officials and other decision-making stakeholders to obtain timely authorizations.

Best Practices

Best practices, determined through experience and recorded in clearly written protocols, help to increase safety of personnel and efficiency of operations. To ensure that best practices are followed, responders must undergo appropriate training and have access to the protocols for their specific tasks. This section provides general categories and tools for facilitating best practices, as well as specific examples of operational best practices as they were carried out during the DWH response.

Multilayered Approach (General Recommendations). In responding to a major offshore oil spill, the key for effective ISB operations is to have a multilayered approach, with each layer having its own clear plan, and to take all environmental and safety factors into consideration before ignition. The “layers” in the approach are as follows:

- Ability to assemble ISB experts (with previous spill experience), boom manufacturers, USCG responders, trained spotters, and other personnel who have had previous training and/or experience with specific ISB operations.
- Quick access to regulatory agencies and other decision-makers in the event that a permit/authorization is required.
- A library of analytical resources regarding oil type, weathering and emulsion effects, meteorological effects, particulate monitoring, and residue type and behavior.
- A carefully crafted training program for new responders and stakeholders who may become involved in ISB operations.
- Equipment, vessels, and aircraft that have been staged in close proximity to potential spill sites, and resources (e.g., fire boom) that can be obtained quickly.
- Trained sealife responders (e.g., NOAA-trained and vetted turtle observers) who can help ensure that wildlife are protected and avoided during ISB operations.
- Attention to other (simultaneous) operations that may affect a planned burn or resources.
- Redundant resources to enable the capability of initiating multiple burns simultaneously.
- A variety of approaches that can be tailored to the specific situation encountered with each oil slick (e.g., feeding the burn, burning outside the fire boom, and using ignition-enabling agents).
- Ability to predict the direction and behavior of the plume, as well as estimate the burn volume accurately.
- A support staff onshore that can set up the communications technology, provide real-time maps of spill locations, analyze and document data provided by on-scene observers, coordinate missions, and maintain a constant supply of resources.
- Emergency vendor contracts that would be needed to deploy the equipment and resources mentioned here.

Support Tools (Facilitating Best Practices). A number of documents can be created and distributed in advance as a part of an overall response plan. These documents, including the following, are valuable response tools:

- ISB Permits/Authorizations
- ISB Operations Plan
- ISB Group Checklist
- ISB Health and Safety Plan
- Air Sampling and Analysis Plan
- Air Quality Monitoring Form
- Burn Volume Calculation Protocols
- Wildlife Identification Manuals (region-specific)
- Wildlife Spotter Protocols
- Wildlife Observation Form
- ISB Training Materials
- Burn Volume Estimation Form
- Aerial Spotter Documentation Form

DWH On-Site Operations (Specific Best Practices). The ISB Tasks Forces responding to the DWH accident not only used but also further developed a number of operational best practices, which are summarized here.

Background. The spill occurred at the Macondo site in the Gulf of Mexico’s Mississippi Canyon 252, approximately 42 nautical miles offshore from Southeast Pass, Louisiana. The released product was a light, sweet Louisiana crude oil. Appendix A shows the location where controlled ISBs were initiated. As shown on the map **(Fig. A-3),** a majority of the controlled burns were initiated northeast-northwest of the source. The latitudes and longitudes were used in reporting the approximate plume locations to the EPA. The first ISB Task Force for the DWH response was conducting a burn within 48 hours of notification that the ISB response method was needed to supplement the mechanical recovery operations. Between 28 April and 19 July 2010, the Controlled In-Situ Burn (CISB) Group (under the Offshore Operations Branch) conducted approximately 400 burns within the specified and approved CISB Burn Area typically within 3 to 15 miles of the Mississippi Canyon 252 oil spill source. On 15 July, the subsea cap was successfully installed, with no more oil traveling to the surface.

Resources. At the height of the response, fewer than 100 people, approximately 30 vessels, 2 aircraft, and 23,000 ft of fire boom supported the ISB operations effort. Three ISB Task Forces were deployed, each supporting four to five burn teams. Each team comprised two 65- to 100-ft shrimp boats for pulling boom, two or three larger vessels for Command, safety/fire control and boom supply/repair, and multiple smaller boats for ignition and repairs. Most of the vessels deployed from Houma, Louisiana. Supporting these teams were approximately 10 members of the aerial surveillance and spotting team, which operated two King Air aircraft to search for and initially assess oil slicks and then to help spot and guide teams to increase performance while recording burn areas and durations to help estimate burn volumes. The teams were also supported by a number of specialists onshore and in the field, such as those involving sealife, geographical information, ISB analysis, data processing, and meteorology. The onshore ISB team performed a majority of the documentation tasks. The CISB Group was continuously staffed with technical advisors, USCG personnel, and contracted resources. Safety and air-monitoring industrial hygiene specialists were positioned on the Command vessel for daily monitoring of each ISB Burn Team and other support personnel.

Operational Periods. With the exception of bad weather days, the ISB Task Forces and all support vessels were available on location by daybreak each day. They experienced minor impact resulting from seismic surveys being conducted in and around the

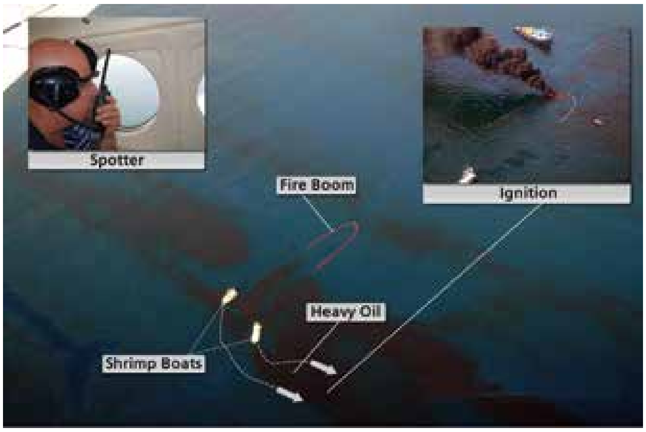

Fig. 4—Spotters directing operations from the air.

spill source area. Throughout each burn day, ISB Burn Teams were guided to the heaviest concentrations of oil by the spotter aircrafts. Using two King Air fixed-wing spotter planes, two separate crews, and two sorties, the CISB Technical Advisors/Spotters and Documenters were able to stay on location for typically 7½ hours for continuous aerial observations. The first flight departed in the morning at 0730 hrs. Before that flight returned to the Houma Airport, the second spotter plane departed and flew to the burning locations to take over spotting and documenting tasks. When the first plane returned to the spill location, the second plane left to refuel. Several attempts were made to fly the spotter aircraft earlier and later to get more spotting time coverage, but the angle of the sunlight was too low to perform effective spotting and oil-thickness characterization.

Simultaneous Operations. The ISB Burn Teams carried out operations simultaneously with both the mechanical skimming teams and the dispersant group. They used burn circles to place a boundary around the burn operations (Appendix A). The circular boundary allowed them to optimize their burning operations in the vicinity of the source where the mechanical skimming vessels were working. All teams were required to respect these boundaries, which was key in maintaining safe simultaneous operations.

Spotting and Vectoring. The ISB Burn Teams were directed to dark oil by Spotters **(Fig. 4)** without independently towed deflection (enhanced booming). Once on station, Spotters circled the area to observe oil concentrations and direct vector fire teams to the more concentrated oil while avoiding sheens of insignificant thickness. A log of events (times of arrival/departure for the spotter aircraft, times of ignition, and durations of burn) and photos were recorded and well documented for each of the burn days. Toward the end of the response and after capping the subsea wellhead, the oil was more weathered and ignition became more challenging but was still accomplished for an additional 4 days.

To facilitate identification and communications with the spotters in the aircraft above, the ISB Burn Team vessels were color-coded using tarps suspended over the back deck of the boats. The Automatic Identification System (AIS) was continually used to allow for quick identification of the offshore burn vessels from the air and confirm their positions. Implementing this method of aerial guidance for the burn teams was one of the major keys to success of the CISB operations. Spotters were required to effectively communicate to both the King Air pilots and the lead vessel captain on the burn team. This important communication optimized the burn teams' time in containing as much oil as possible and became a best practice. Because the oil spread in windrows owing to wind and wave action, it was difficult for the vessel crews to tell which way to navigate to stay in the higher-concentration oil. Aerial observations from 1,000 to 1,500 ft made it possible to easily provide "step" navigation communications to the burn-team vessel captains in order to increase the fire-boom oil encounter rate.

Sealife Monitoring. There were as many as five sealife observers on the vessels at any given time. These observers were a

Fig. 5—Simultaneous burns conducted on 18 June 2010.

TABLE 2—PHASE I CONSIDERATIONS—ISB APPROPRIATENESS

Consideration	Specifics
Subsea or surface spill?	Subsea spill 5,000 ft below the water's surface
Continuous release or single release?	Continuous release
Type of hydrocarbon?	Sweet Louisiana crude
Proximity from populations?	Approximately 40 nautical miles
Ability of other response options to adequately remove the oil?	All other options were successful; however, mechanical recovery needed to be supplemented.
Regional guidelines/regulations?	Pre-approved zone

part of the offshore burn teams and monitored for any turtle activities. As the size of the operation grew, the sealife monitoring plan was augmented with additional trained and qualified turtle observers and observer trainees. No turtles or other sealife were spotted in or near the fire boom during operations.

Safety. Attention to safety was always paramount. The ISB Fire Teams demonstrated that, if the wind blew smoke plumes toward them, they could simply reposition their vessels to avoid any smoke impact. There were also no air-monitoring readings outside the established safe parameters. The only exceptions were occasional temporary excursions when exhaust vapors from the fire-boom pump engine and outboard motor exhausts caused temporary high readings. These pumps were positioned on the back decks of the shrimp boats in a highly ventilated area during operations.

In the course of the approximately 400 burns, only two were intentionally extinguished. The first occurred with the longest burn of 11 hours and 48 minutes. Although still continuing to catch oil and feed into the fire boom, crews began to show signs of fatigue and were directed to intentionally extinguish the fire by increasing towing speed and pulling the boom over the remaining fire. The second of these occurred when an area of fire spilled out of the containment boom. Although still safe, crews opted to extinguish the fire using deck-mounted water cannon equipment to demonstrate its safety utility.

Large-Volume and Long-Duration Burns. A significant amount of oil was burned on 18 June with a total estimated calculated volume of 50,000 to 70,000 bbl in 16 burns (NRT 2011). Seas were unusually calm with very little wind and waves. **Fig. 5** shows simultaneous burns on that day. It was repeatedly proven that safe burning operations can be sustained by vectoring vessels into streams of oil, thereby feeding the on-water combustion process. By maintaining a high level of safety awareness, responders were able to feed oil into an ongoing burn throughout the response because of the low flammability of the slicks being encountered. A careful and continuous monitoring of the burns allowed responders to ensure that burning could not propagate forward toward the vessels faster than the towing speed of approximately ½ knot (ARPEL 2006; Hiltabrand and Roderick 1999). Because of the condition of the encountered oil (weathered and emulsified), the "feeding" of oil into an existing burn was always safe and effective. Several long-duration burns, lasting more than 10 hours, were also conducted in mid-June. These burns were not necessarily high volume, but had very long continuous combustion. This operation demonstrated that feeding oil into the fire boom sustains a continuous combustion of up to 11 hours and 48 minutes, as seen on 16 June (see Appendix A).

Boom Performance. Five different fire-boom types were used during the response to achieve approximately 400 safe and very effective controlled ISBs. The water-cooled boom proved to have the most longevity with less damage from the fire. Its higher success rate was also due to its flexibility in withstanding fatigue stress from the constant wave action. The boom systems had to remain deployed in the water during the night, awaiting the start of the next day's work shift.

Burn-Volume Calculation. As shown in Appendix B, burn-volume calculations for each burn included a minimum and maximum estimate. The minimum volume estimate is based on the lower of any multiple air/surface estimates of burn area, the duration of burn, and a burn rate of 0.05 gallon/ft^2/minute, the rate commonly associated with the burning of an emulsified crude oil (typically from 25 to 40%) (ASTM 2003; USCG 2003b; Federal Interagency Solutions Group 2010). The maximum volume estimate is based upon the best upper estimates of the burn area, the duration of burn for each of those areas, and a burn rate of 0.07 gallon/ft2/minute, which is the rate commonly associated with the controlled burning of crude oil that has been emulsified to approximately 10 to 20% (ASTM 2002; Buist et al. 2003; Federal Interagency Solutions Group 2010).

Conclusions From the DWH Experience. Approximately 400 burns successfully removed between 220,000 and 310,000 bbl of oil (according to USCG, NOAA, and EPA estimates) to minimize its effect on Gulf of Mexico coastlines and sealife. The success of this response, a milestone in the spill-response industry, supports the conclusion that controlled ISB is a safe, effective, and proven technology (Allen et al. 2011). When conditions warrant and the mechanical recovery option needs to be supplemented, ISB teams should be activated immediately. The sooner the teams can get to the spilled oil with the right equipment, the quicker the spilled hydrocarbon impact can be minimized.

Most of the significant lessons learned during the ISB operations of the DWH accident involved the importance of being pre-

TABLE 3—PHASE II CONSIDERATIONS--IGNITABILITY

Consideration	Specifics
Oil slick thickness?	At least 2 mm with the aid of fire boom
Emulsification?	Not measured
Evaporation?	Not measured
Wind and waves?	83-day window Wind less than 20 knots and waves less than 5 ft were experienced on more than half of the available burn days

TABLE 4—PHASE III CONSIDERATIONS—SITE SAFETY*

Consideration	Specifics
Personnel exposure	An industrial hygienist safety specialist helped to minimize the possibility of potential exposure by monitoring in-field personnel. Other teams also monitored air quality, including NOAA, the US EPA, and the Florida Department of Environmental Protection. For responders, vapor concentrations were tested before every ignition.
Ignition control	Ignition effects were predictable because the oil's volatility had been reduced as a result of evaporation and emulsification. VOC concentrations were measured, and permission was obtained before each ignition.
Fire control	A fire-control vessel and crew were on site to address any fire concerns, but careful attention to proximity and wind direction prevented any safety events from occurring. The command vessel and other support vessels had water-cannon capability, and the potential for fire spreading was assessed before every ignition.
Vessel safety	Fireboom-towing vessel crews could easily extinguish fires by simply advancing tow speed. Vectoring and careful vessel coordination was maintained throughout controlled ISB operations.

* Note: No ISB safety-related incidents were reported during the DWH response.

pared in the areas of training, resource staging/availability, and communication methods/equipment. One of the primary keys to the success of the controlled ISB operations during the DWH response was the ability to use aerial surveillance (Spotters) to locate the oil and direct resources from the air.

Case Study: Controlled ISB Decision Phases During the DWH Response

The DWH response provides an ideal case study for a warm-water, offshore response with a continuous release of hydrocarbons from a blowout. Because the proximity to populations was approximately 40 nautical miles and "fresh" oil slicks were available for burning daily, the ISB response team had an unprecedented opportunity to see the technology succeed on a very large scale. The DWH spill location had been pre-approved for the use of controlled ISB. **Table 2** provides the Phase I consideration specifics that apply to controlled ISB appropriateness and feasibility.

The considerations involving ignitability were also, in general, favorable during the DWH response. **Table 3** provides a breakdown of those factors. Additional information about simultaneous operations and burn locations can be found in Appendix A.

Table 4 provides the site-safety considerations, which are evaluated at the site immediately before igniting a controlled ISB.

Conclusions

Although some regions of the world still consider controlled ISB to be an alternative response option and have taken a guarded approach to authorizing its use, this response option actually has a long history of research, testing, and use during oil-spill responses. Having further proven itself on a grand scale during the DWH response, controlled ISB, under the right conditions, is now considered by many to be a viable, conventional response option for offshore oil spills. In some conditions, controlled ISB is considered to be the only effective option [e.g., it may be the "best available technology for ice conditions" (ASTM 2002)].

When considering the environmental tradeoffs for controlled ISB, the pros far outweigh the cons. Although there are some limitations based primarily on the location and conditions, controlled ISB can remove as much as 99% of an oil slick and requires the use of significantly fewer resources than other options. The USCG explains the tradeoffs: "The bum or no-bum issue is essentially a tradeoff and, in many situations, the environmental threats posed by the burning process will be much less than leaving the oil on the water surface" (Walker et al. 2003). Controlled ISB can remove the spilled oil safely, efficiently, and rapidly, and it lessens the need for disposal and storage.

Analysis of ISB results from the DWH accident clearly support the confirmation of controlled ISB, under the right conditions, as a conventional response option for hydrocarbon spills offshore.

References

ACS. 2008. *Alaska Clean Seas Technical Manual, Volume I: Tactics Descriptions,* revised May 2008. Prudhoe Bay, Alaska: Alaska Clean Seas (ACS).

Allen, A.A., Mabile, N.J., Jaeger, D. et al. 2011. The Use of Controlled Burning during the Gulf of Mexico Deepwater Horizon MC-252 Oil Spill Response. *Proc.,* 2011 International Oil Spill Conference, Portland, Oregon, USA, 23–26 May, Vol. 2011, No. 1, Paper No. 2011-194. http://dx.doi.org/10.7901/2169-3358-2011-1-194.

ARPEL Emergency Response Planning Working Group and Fingas, M. 2006. A Guide to In-situ Burning of Oil Spills on Water, Shore, and Land. ARPEL Environmental Guideline No. 40-2006, Regional Association of Oil and Natural Gas Companies in Latin America and the Caribbean (ARPEL), Ottawa, Ontario (November 2006), http://www.arpel.org/media/apps/library/324/files/AEG40-In%20situ%20burning.pdf.

ASTM F2230-02 Standard Guide for In-situ Burning of Oil Spills on Water: Ice Conditions. 2002. West Conshohocken, Pennsylvania: ASTM International. http://dx.doi.org/10.1520/F2230-02.

Aurell, J. and Gullett, B.K. 2010. Aerostat Sampling of PCDD/PCDF Emissions from the Gulf Oil Spill In Situ Burns. *Environ. Sci. Technol.* **44** (24): 9431–9437. http://dx.doi.org/10.1021/es103554y.

Bernhardt, L. and Hart, C. 1995. *In Situ Burning Policy and Operational Guidelines.* Richland, Washington: Spill Policy and Prevention Section, Northwest Area Committee, Washington State Department of Ecology.

Buist, I.A. 2004. *In Situ* Burning for Oil Spills in Ice-Covered Waters. Presented at the Interspill 2004 International Conference & Exhibition, Trondheim, Norway, 14-17 June.

Buist, I.A., Coe, T., Jensen, D. et al. 2003b. Oil Spill Response Offshore, In-Situ Burn Operations Manual. Final Report, No. ADA418267, US Coast Guard Research and Development Center, Groton, Connecticut (March 2003), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA418267.

Buist, I.A., Dickins, D., Majors, L. et al. 2003. Tests to Determine the Limits to In Situ Burning of Thin Oil Slicks in Brash and Frazil Ice.

Proc., 10th International Oil Spill Conference, Baltimore, Maryland, USA, 373–381.

Fingas, M. 2004. Weather Windows for Oil Spill Countermeasures. Report, Prince William Sound Regional Citizens' Advisory Council (PWS-RCAC), Anchorage, Alaska (January 2004), http://www.pwsrcac.org/docs/d0002500.pdf.

Fingas, M.F. 1997. *Compilation of Physical and Emissions Data: Newfoundland NOBE Offshore Burn Experiment.* Ottawa, Ontario: Environment Canada.

Fingas, M.F. 1999. In-Situ Burning of Oil Spills: A Historical Perspective. In *In Situ Burning of Oil Spills. Workshop Proceedings, New Orleans, LA, November 2-4, 1998,* W.D. Walton and N.H. Jason, NIST SP 935. Gaithersburg, Maryland: NIST Special Publication, National Institute of Standards and Technology. http://fire.nist.gov/bfrlpubs/fire99/PDF/f99019.pdf.

Fingas, M.F. and Punt, M. 2000. In-Situ Burning: A Cleanup Technique for Oil Spills on Water. Report, Environment Canada, Ottawa, Ontario (February 2000).

Florida Department of Environmental Protection. 2012. Division of Air Resource Management, http://www.dep.state.fl.us/air/.

Hayward, R. ed. 2008. *ExxonMobil Oil Spill Response Field Manual,* revised 2008 edition. Annandale, New Jersey: ExxonMobile Research and Engineering Company.

Helland, R.C., Smith, B.L., Hazel, W.E. III et al. 1997. Underwater Recovery of Submerged Oil During a Cold Water Response. *Proc.,* 1997 International Oil Spill Conference, Ft. Lauderdale, Florida, USA, 7–10 April, 765–772.

Hiltabrand, R.R. and Roderick, G.S. 1999. Fire-Resistant Booms: From Testing to Operations. *Proc.,* International Oil Spill Conference, Groton, Connecticut, USA, 10 March, Vol. 1999, No. 1, 535–539, http://dx.doi.org/10.7901/2169-3358-1999-1-535.

IPIECA. 2000. Choosing Spill Response Options to Minimize Damage: Net Environmental Benefit Analysis. Oil Spill Report Series, Vol. 10, International Petroleum Industry Environmental Conservation Association, London http://www.ipieca.org/publication/choosing-spill-options-minimize-damage-net-environmental-benefit-analysis.

ITOPF. 2002. Fate of Marine Oil Spills. Technical Information Paper, No. 2, The International Tanker Owners Pollution Federation Limited (ITOPF), London, http://www.itopf.com/_assets/documents/tip2.pdf.

Lehr, B., Bristol, S., and Possolo, A. 2010. Oil Budget Calculator: Deepwater Horizon. A Report to the National Incident Command. Technical Documentation Report, Coastal Response Research Center (CRRC), Durham, New Hampshire (November 2010), http://www.crrc.unh.edu/publications/OilBudgetCalcReport_Nov2010.pdf.

Lubchenco, J., McNutt, M., Lehr, B. et al. 2010. BP Deepwater Horizon Oil Budget: What Happened To the Oil? Final Report, National Oceanic and Atmospheric Administration (NOAA), Washington, DC (August 2010), http://www.restorethegulf.gov/sites/default/files/imported_pdfs/posted/2931/Oil_Budget_description_8_3_FINAL.844091.pdf.

McCourt, J., Buist, I., and Mullin, J. 1999. Operational Parameters for In Situ Burning of Six U.S. Outer Continental Shelf Crude Oils. *Proc.,* International Oil Spill Conference, Groton, Connecticut, USA, March, Vol. 1999, No. 1, 1261–1263, http://dx.doi.org/10.7901/2169-3358-1999-1-1261.

Michel, J. 2007. Submerged Oil - State of the Practice and Research Needs. Research Report, Coastal Response Research Center, Durham, New Hampshire (July 2007), http://www.crrc.unh.edu/workshops/submerged_oil/submerged_oil_workshop_report.pdf.

Michel, J. and Gait, J.A. 1995. Conditions Under Which Floating Slicks Can Sink in Marine Settings. *Proc.,* International Oil Spill Conference, Long Beach, California, USA, 27 February–02 March, API Publication No. 4620, 573–576, http://dx.doi.org/10.7901/2169-3358-1995-1-573.

Michel, J., Scholz, D., Warren, S.R. Jr. et al. 2005. In-*situ* Burning: A Decision-Maker's Guide to In-*situ* Burning. Regulatory Analysis and Scientific Affairs Publication Number 4740, American Petroleum Institute, Washington, DC (April 2005), http://www.api.org/environment-health-and-safety/clean-water/oil-spill-prevention-and-response/~/media/4bdbd6aabd534bf1b88eb203c6d8b8f4.ashx.

Middlebrook, A.M., Murphy, D.M., Ahmadov, R. et al. 2012. Air quality implications of the *Deepwater Horizon* oil spill. PNAS 109 (50): 20280-20285. http://dx.doi.org/10.1073/pnas.1110052108.

NIOSH. 2011. Emergency Responder Health Monitoring and Surveillance. Draft 1.2, CDC/National Instutiute for Occupational Health and Safety (NIOSH), Atlanta, Georgia (01 February 2011), http://www.cdc.gov/niosh/docket/review/docket223/pdfs/ERHMSDocument-Draft1_31.pdf.

NOAA. 2010. Characteristics of Response Strategies: A Guide for Spill Response Planning in Marine Environments. Joint Summary Report, American Petroleum Institute (API)/National Oceanic and Atmospheric Administration (NOAA)/U.S. Coast Guard (USCG)/U.S. Environmental Protection Agency (EPA), Seattle, Washington (June 2010), http://docs.lib.noaa.gov/noaa_documents/NOS/ORR/910_response.pdf.

NOAA. 2011. Air pollution levels from Deepwater Horizon spill similar to large urban area. *NOAA News* (19 December 2011), http://www.noaanews.noaa.gov/stories2011/20111219_dwhairquality.html (accessed May 2012).

NRT. 2011. On Scene Coordinator Report Deepwater Horizon Oil Spill. OSC Report, National Response Team, Washington, DC (September 2011), http://www.uscg.mil/foia/docs/dwh/fosc_dwh_report.pdf.

Overstreet, R. and Galt, J.A. 1995. Physical Processes Affecting the Movement and Spreading of Oils in Inland Waters. HAZMAT Report 95-7, NOAA/Hazardous Materials Response and Assessment Division, Seattle, Washington (September 1995), http://response.restoration.noaa.gov/sites/default/files/inland.pdf.

Papp, R.A. Jr. 2011. Incident Specific Preparedness Review (ISPR) Deepwater Horizon Oil Spill. Final Action Memorandum, US Coast Guard, Washington, DC (18 March 2011), http://www.uscg.mil/foia/docs/dwh/bpdwh.pdf.

Potomac Management Group (PMG) and Environmental Research Consulting (ERC). 2002. Risk Assessment for the Coast Guard's Oil Spill Prevention, Preparedness, and Response Program (OSPPR). Phase I: Concept Development, Risk Characterization, and Issue Identification. RBDM Assessment Report, Contract No. DTCG23-00-MM3A01, US Coast Guard Office of Response (G-MOR), Washington, DC (August 2002), http://www.environmental-research.com/erc_reports/ERC_report_13.pdf.

Potter, S., Buist, I., Trudel, K. et al. 2012. Spill Response in the Arctic Offshore. Final Report, American Petroleum Institute (API) Arctic Oil Spill Task Group/Joint Industry Programme on Oil Spill Recovery in Ice (JIP), Washington, DC (02 February 2012), http://www.api.org/~/media/files/ehs/clean_water/oil_spill_prevention/spill-response-in-the-arctic-offshore.ashx.

Region VI Regional Response Team (RRT). 1994. RRT VI: In-Situ Burn Plan, Part I & II. Operations Section. Technical Report, Marine Spill Response Corporation (MSRC), Lake Charles, Louisiana (14 March 1994).

Rymell, M. 2009. RP595 Sunken and submerged oils—behaviour and response: A report for the Maritime and Coastguard Agency. BMT Cordah Report (Final Report), No. S.MCA.019, BMT Cordah, Hampshire, UK (27 February 2009), http://www.dft.gov.uk/mca/s_mca_019_sunken__and__submerged_oils_final_report_270209_pub_1.pdf.

S.L. Ross Environmental Research. 1995. Demulsifiers and Modified Heli-Torch Fuels to Enhance In-Situ Burning of Emulsions. Final Report, Transport Canada/Alaska Clean Seas (ACS), Anchorage, Alaska/Ottawa, Ontario (March 1995).

Schaum, J., Cohen, M., Perry, S. et al. 2010. Screening Level Assessment of Risks Due to Dioxin Emissions from Burning Oil from the BP Deepwater Horizon Gulf of Mexico Spill. *Environ. Sci. Technol.* **44** (24): 9383–9389. http://dx.doi.org/10.1021/es103559w.

United States Government Accountability Office (GAO). 2010. Efforts to Identify Arctic Requirements Are Ongoing, but More Communication

Fig. A-1—16 June burn lasting 11 hours, 48 minutes.

about Agency Planning Efforts Would Be Beneficial. Report to Congressional Requesters GAO-10-870, US Coast Guard, Washington, DC (September 2010), http://www.gao.gov/assets/320/311302.pdf.

US Code of Federal Regulations. 1996. 33 CFR § 155.1010, Oil or Hazardous Material Pollution Prevention Regulations for Vessles, Subpart D—Tank Vessel Response Plans for Oil—Purpose [CGD 91-034, 61 FR 1081]. http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&SID=eddbedaf9c9739d0c0ce79d3ea762279&rgn=div8&view=text&node=33:2.0.1.5.24.4.161.1&idno=33 (accessed May 2012).

Velez, P., Johnsen, H.G., Steen, A. et al. 2011. Advancing Oil Spill Preparedness and Response Techniques for Arctic Conditions. *Proc.,* International Oil Spill Conference, Portland, Oregon, USA, 23–26 May, Vol. 2011, No. 1, Paper No. 2011-105. http://dx.doi.org/10.7901/2169-3358-2011-1-105.

Walker, A.H., Michel, J., Benggio, B. et al. 2003. *Selection Guide for Oil Spill Applied Technologies: Volume I—Decision-Making,* (updated January 2003). Cape Charles, Virginia: Scientific and Environmental Associates, Inc. http://archive.orr.noaa.gov/book_shelf/676_SelGuide.pdf.

Appendix A—DWH Daily Controlled Burn Report and Burn Locations

Burn attempts were conducted over an 83-day period, with successful burns completed on 40 days. Although some days were spent securing personnel, equipment, and vessels, as well as training new responders, most of the down days were a result of wind and sea conditions that precluded the successful containment of oil within fire boom

(i.e., approximately 1- to 2-m, or 3- to 4-ft waves).

Fig. A-1 is a photo from one of the longest burns (16 June) where a water-cooled fire boom was towed through an exceptionally long stretch of oil, lasting 11 hours and 48 minutes. During that burn, the minimum to maximum estimated range of oil removed was 5,956 to 8,339 bbl. There was another noteworthy day (18 June) when several long burns using a water-cooled boom and an early-generation curtain boom protected by an outer, sacrificial layer resulted in the removal of 50,000 to 70,000 bbl in one day.

Fig. A-2 illustrates the approximate location of the burn initiations, and Fig. A-3 shows the burn circles that were designed to prevent conflicts during simultaneous operations.

Appendix B—Burn-Volume Estimation

ISB technical advisors refined protocols for estimating the burn volumes during the DWH response. Spotters and Documenters monitored each controlled ISB from aircraft and recorded information to describe the changing scene and conditions. This information was recorded as frequently as necessary depending upon the rate of change of the burn area and the number of burns observed. As the burn area grew, the Documenter logged the burn times and sizes, and then provided this data to the ISB Data Analyst immediately after each operational period. An ISB Data Analyst (employed by O'Brien's Response Management) calculated the volumes using two equations, minimum and maximum, which took into account the estimated variable crude-oil emulsions collected in the fire-boom systems that could affect burn volumes. Documenters used the "U" Configuration Chart **(Fig. B-1),** which is a fractional area estimation of a 500-ft boom in a "U" configuration,

Fig. A-2—Map of DWH controlled ISB locations.

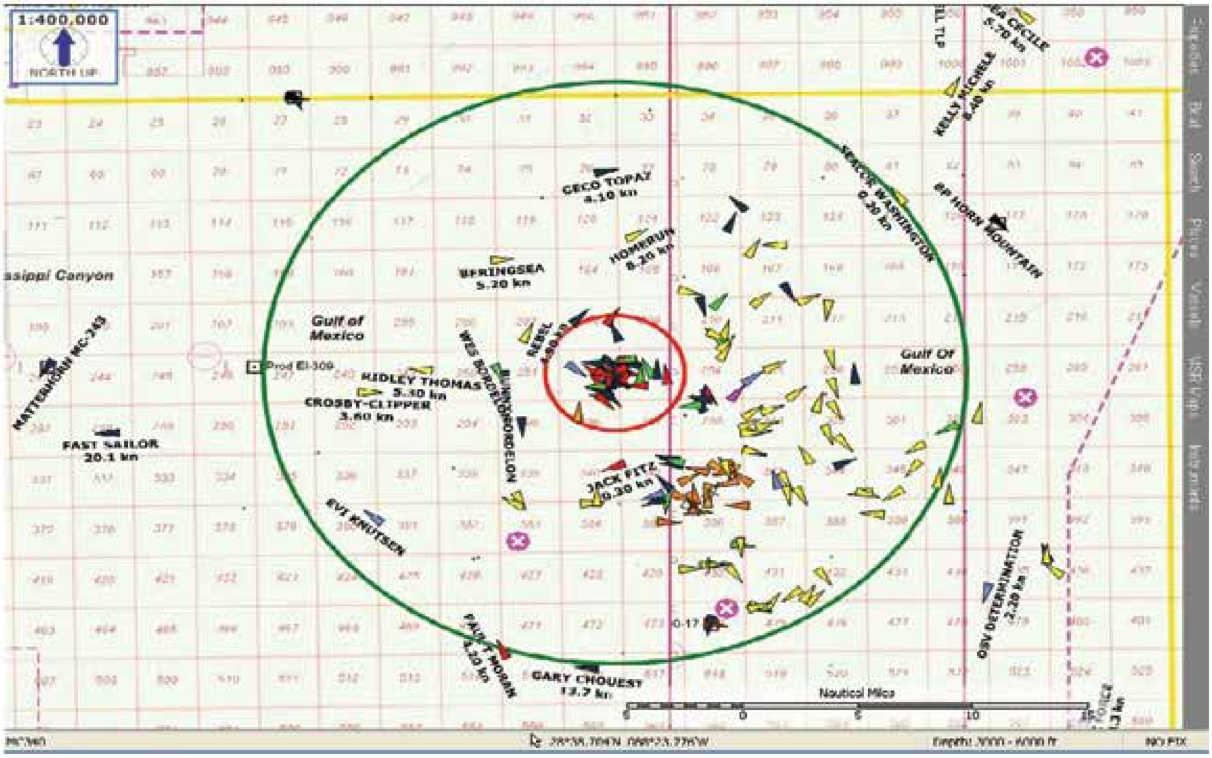

Fig. A-3—Burn “circles,” zones for maintaining safe distances.

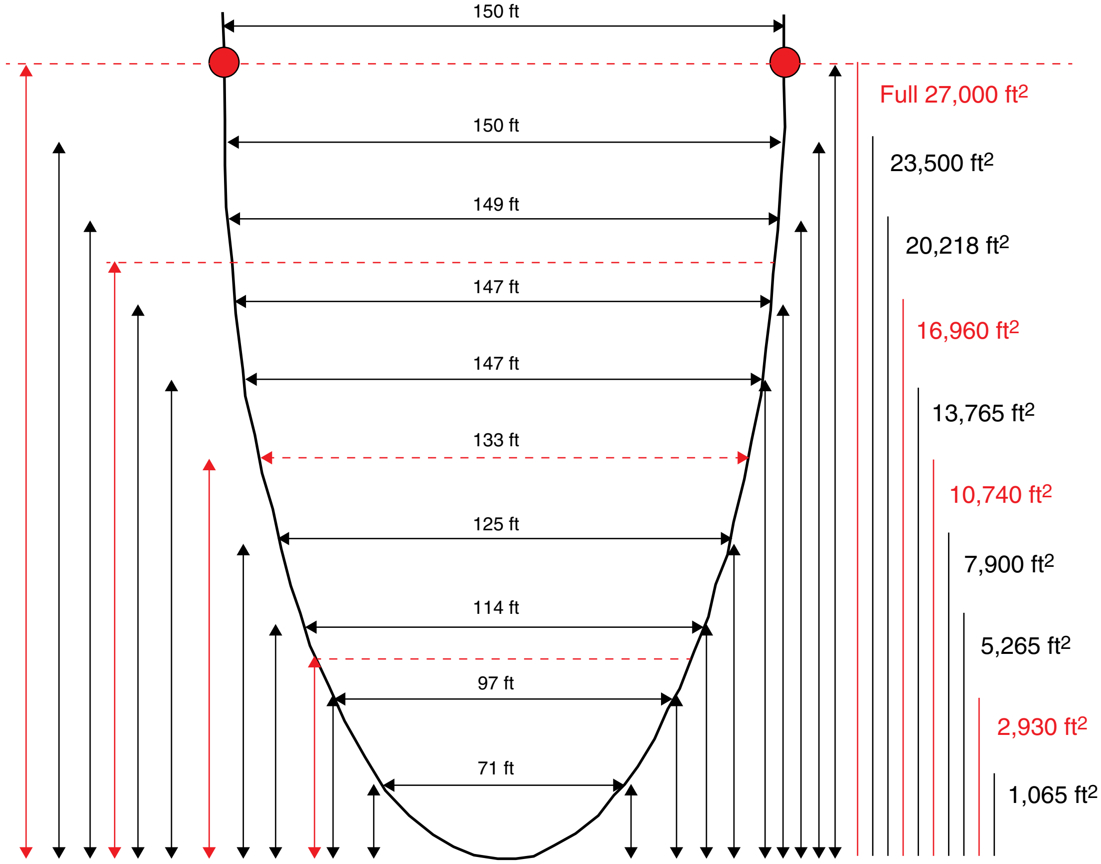

Fig. B-1—U-Configuration Chart providing fractional area estimation of 500-ft boom in the “U” configuration.

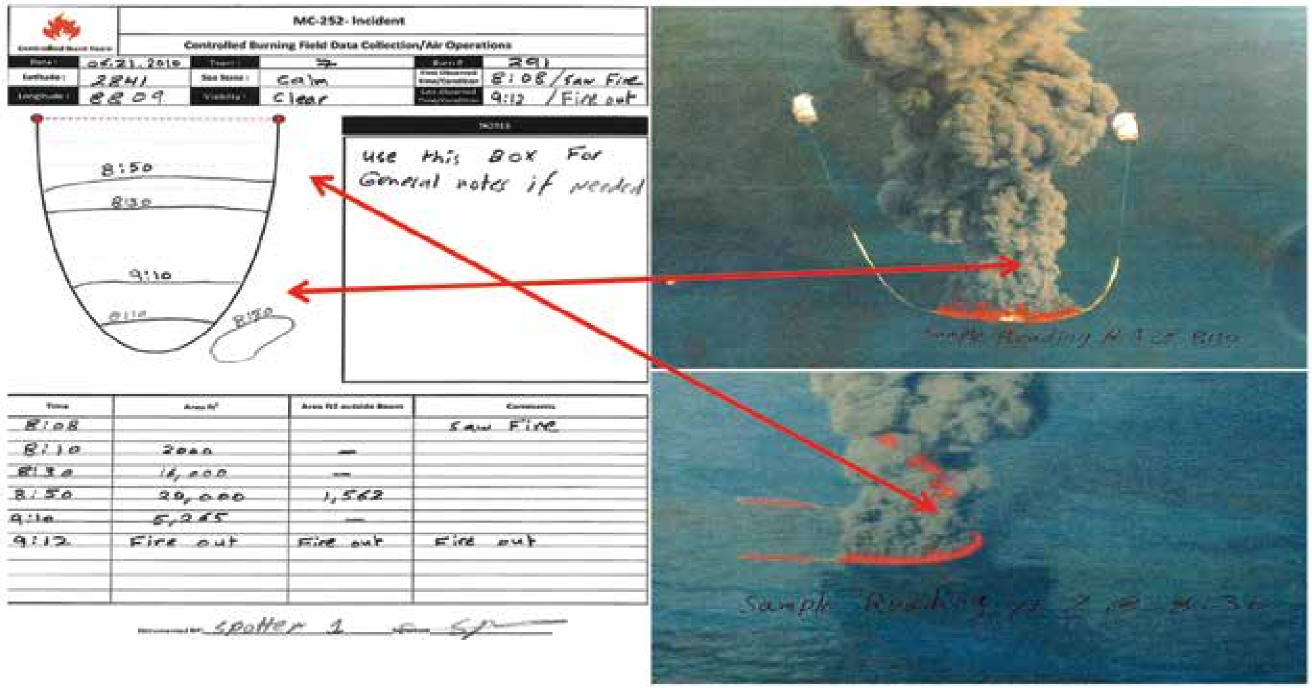

Fig. B-2—Field Data Collection Sheet used by Air Operations during the DWH response.

and the Field Data Collection Sheet **(Fig. B-2)** to record the most accurate data possible for estimating the burn area. The burn volumes were calculated by the product of the estimated burn area, recorded burn duration, and an established upper and lower burn rate range.

The ASTM's *Standard Guide for In-Situ Burning of Oil Spills on Water* establishes that "most crude oil burns at the rate of about 3 mm/min, which means that the surface of the oil slick regresses downwards at the rate of 3 mm/min. This translates to a rate of about 5000 L/m^2/day (or 100 gal/ft^2/day)," independent of the oil's physical condition or type (ASTM 2002).

Neré J. Mabile is currently a technology theme leader with the Oil Spill Response Technology Team at BP America's Houston office. He has served the oil and gas industry for 30 years, primarily in areas of oil-spill prevention and response. In addition to oil-spill-response technology, his unique skill set also includes integrity management, corrosion engineering, operations, and project management. Most recently, during the response to the Deepwater Horizon accident in 2010, Mabile supported the Controlled In-Situ Burning Team as a technical advisor. In that capacity, he supervised and managed aerial surveillance and spotting operations and helped to remove more than 300,000 bbl of oil from the Gulf of Mexico waters (as estimated by regulatory agencies). He holds an MS degree in environmental science from the University of Alaska, Anchorage.