Final Report

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Development of a Planning Standard for In-Situ Burning Operations

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1. Background

As the oil spill response community has become increasingly aware, developing an adequate response plan or evaluating a plan requires that one address a comprehensive set of elements that may affect the overall success of the response system. For example, in order to adequately evaluate the potential success of an offshore containment and recovery system, the pumping rate of the skimmer, while important, is only one of many elements that must be evaluated. This is exemplified in ASTM F1780, Standard guide for estimating oil spill recovery system effectiveness. This standard includes consideration of the oil slick encounter rate, oil slick thickness changes, the effect of oil slick emulsification, skimmer recovery rate, skimmer efficiency, operating limits imposed by weather and sea conditions, and transit speeds and offloading rates related to storage and transfer operations among other factors. F1780 was initiated in the early 1990s and was based on a computerized response evaluation system that SL Ross has used for clients since 1985. A similar system is proposed for evaluating in-situ burning (ISB) operations, and would consider the following factors:

- Mobilization and transit times
- Variations in slick conditions as a result of spill type (i.e., batch versus blowout)
- Changes in slick thickness
- Changes in slick composition and emulsification
- Lengths of fire-resistant boom that can be effectively managed, and based on this, swath widths
- Slick encounter speeds
- Burn rates
- Degradation of boom as a result of heat exposure
- Burning Offset Distance
- Operating Period

In the project initiation meeting, BSEE requested the following be addressed as well:

1. Identify the range of operating conditions that in situ burning can be used (sea state, winds, ignition window of opportunity for various oil types);
2. Establish the required components of an in-situ burning "system";

3. Identify a methodology to calculate a burn potential based on encounter rate and the parameters selected for the components of a "burn system";
4. Establish minimum performance requirements for the use of firebooms.

BSEE also noted that while the involvement of ASTM was desirable as a tool for building consensus the overall objective was to develop a planning tool that could be used to evaluate ISB response plans irrespective of its potential development as an ASTM standard.

The report that follows is background to a potential guide for evaluating ISB operations. Each of the factors listed above is described as to their significance, and default values and/or acceptable ranges for each are proposed such that an overall model can be developed for evaluating ISB operations. The defaults and ranges are based, as much as possible, on documented literature covering field tests and operational uses of ISB over the past four decades, including:

- Experimental data from the Mobile, Alaska Clean Seas, and Ohmsett test programs in the mid- to late 1990’s
- Field data from burns performed in response to the Macondo spill (2010)

2. Involvement of ASTM

ASTM, formerly the American Society of Testing and Materials, is a globally recognized leader in the development and delivery of standards relating to the quality of products, measuring systems performance, and safety. ASTM’s F20 committee on Hazardous Substances and Oil Spill Response was established in 1975, and currently has jurisdiction over 58 standards related to spill response equipment and its application. Some of these standards may be wholly or partially applicable to BSEE’s role in regulating the exploration and development of offshore oil and natural gas on the U.S. Outer Continental Shelf, in particular new and proposed developments in Arctic waters.

ASTM standards are developed by consensus among members of the various committees, with a balance of membership among producers (i.e., equipment manufacturers and suppliers), users (i.e., regulatory bodies, spill response organizations), and general interest (members who cannot be classified as a producer or user). For example, the current ASTM membership is made up of approximately 100 members, with a close to equal mix of producers, users, and general interest classifications such that voting on standards for approval is not dominated by one sector.

As such, ASTM provides an excellent venue for the development of a planning standard for evaluating ISB operations. The objective of the work described here was to develop a planning standard on the use of in-situ burning to assist in BSEE's regulatory mandate using ASTM's consensus-building approach to resolve contentious issues and refine key elements of the guide. ASTM F20 is welcome to carry forward with this and develop and ASTM standard on the subject, but that is not a primary focus of the work.

The usual course for the development of new standards is for a member spearhead the effort by making a proposal to the applicable subcommittee, establishing a scope for the standard in discussions with the subcommittee, developing a draft for discussion purposes, then shepherding it through series of drafts based upon discussions at the semi-annual F20 meetings and through interaction with subcommittee members between meetings.

The overall work plan involving ASTM included the following main steps:

- A detailed scope of the proposed guide was presented at the October 2014 ASTM F20 meeting;
- The scope and proposed work plan was agreed to in principle as a work item by the F20.15 subcommittee on burning;
- An initial discussion paper was presented at the April 2015 meeting for further consideration by the F20.15 subcommittee;
- Subsequent to the April 2015 meeting, a task group of interested members of the F20.15 subcommittee provided additional comments; and
- A proposed draft standard was presented at the October 2015 meeting for further consideration by the F20.15 subcommittee (Appendix A).
- Based on recommendations from the October meeting a revised draft will be posted to an ASTM work group site for further comment. Subsequent to the April 2016 meeting, the draft will likely go to ballot as a proposed new standard. Based on past experience, approval may take several ballots over a period of one year or more.

3. Key Elements of an In-Situ Burning Standard

3.1 Mobilization and transit times

For the purposes of estimating overall system effectiveness, a start time for operations must be specified relative to the start of the spill. This will allow for changes in spill area, slick thickness, and oil composition (all discussed later) to be incorporated into encounter rate calculations. In general terms, a shorter response time will result in encountering thicker slicks and less emulsified oil, both of which should allow greater overall effectiveness.

As a default value, a mobilization time will be used to account for spill notification and mobilization of response equipment and personnel. Mobilization will be assumed to be 2 hours for dedicated resources and 4 hours for contracted resources, which corresponds to the values used in US federal planning regulations for vessel-related spills. A lesser value could be used if it can be demonstrated and documented through drills and exercises.

Once response resources have been mobilized, equipment and personnel must be transported from response bases to the spill site. The assumed transit speed will be 5 knots for marine transport and 55 km/h (35 mph) for land transport unless otherwise demonstrated through drills and exercises.

3.2 Variations in slick conditions as a result of spill type (i.e., batch versus blowout)

This was discussed at length at the October 2014 ASTM meeting in the context of encounter rates for skimming systems. There was general consensus that a clear distinction needed to be made between the two types of spills, for the following reasons:

- Initial slick thicknesses could be much lower for blowouts, particularly for deep-water blowouts.
- The primary thrust of countermeasures for a blowout spill are likely to be near the spill site, where the oil would have had little time to weather, specifically in terms of evaporative losses and emulsification.
- As a result, countermeasures would likely be dealing with relatively fresh oil on an ongoing basis. In contrast, a single batch-type discharge (i.e., from a tanker spill) would result in significant changes in slick thickness, oil viscosity, and water content over time.
- For the response to a blowout spill, the relatively small area would lend itself to an effective surveillance program, which could direct countermeasures to areas of relatively thick oil for maximum overall effectiveness.

3.3 Changes in slick thickness over time

Changes in slick thickness over time were also discussed at length at the October 2014 ASTM meeting in the context of encounter rates for skimming systems. It is recommended that a similar scheme to that being developed as that for the skimming system evaluation, specifically the proposed modifications to F1780, Standard Guide for Estimating Oil Spill Recovery System Effectiveness. For that work, the present slick thickness proposal is as follows:

Tanker spills: worst-case discharges

- Use the recommended Genwest thickness values as a default for batch releases (Table 1 below)
- Allow the use of computer spill modeling for larger batch releases that may have greater initial slick thickness
- Allow the use of increased slick thicknesses (i.e., greater than default) only if the overall response plan includes the use of aerial surveillance to target thick slicks for maximum effectiveness

Blowout spills

- Use 0.050 mm (0.050 µm) (0.002 inches) as the default slick thickness for near-source countermeasures
- Allow the use of computer spill modeling for blowout releases, using a maximum value of 0.100 mm (0.004 in) for near source countermeasures only if the overall response plan includes the use of aerial surveillance to target thick slicks for maximum effectiveness

Table 1: Recommended slick thickness, Genwest report (page 34)

Time from start of spill, h	Slick thickness, inches	Slick thickness, mm
12	0.1	2.5
36	0.05	1.3
60	0.025	0.63

A detailed discussion of the proposed slick thicknesses for blowout spills in contained in Appendix B. At the October 2015 ASTM meeting, it was agreed to approach Genwest with the Appendix B discussion paper to attempt to generate a discussion and justification for the greater slick thicknesses proposed in their report.

3.4 Changes in slick composition and emulsification

Emulsification has a significant effect on overall effectiveness, and can severely limit the window of opportunity for burning:

- Little effect on oil removal efficiency (i.e., residue thickness) for low water contents up to about 12.5% by volume;
- A noticeable decrease in burn efficiency with water contents above 12.5%, the decrease being more pronounced with weathered oils; and
- Zero burn efficiency for emulsion slicks having stable water contents of 25% or more. Some crudes form meso-stable emulsions that can be burn efficiently at much higher water contents. Paraffinic crudes appear to fall into this category.

Not all oils emulsify, but as a default it should be assumed that all crude oils and heavy refined products would to some extent. The following emulsification schedule should be used unless documented otherwise through laboratory analysis and computer modeling (ref: ASTM WK41247 * New Test Method for Standard Test Method for Method for the Evaluation of the Stability of Water-in-oil Mixtures Formed from Crude Oil and Petroleum Products Mixed with Saline Water).

Table 2: Recommended emulsification schedule

Time from start of spill, h	Emulsified water content, %
24	33
48	50
72	75

3.5 Lengths of fire-resistant boom that can be effectively managed, and based on this, swath widths

Based on extensive experience in the response to the Macondo blowout, 500-foot (150-metre) lengths of booms were found to be manageable through the containment and burning operations. This is recommended as a default maximum boom length unless greater boom lengths can be demonstrated and documented.

Based on this, a default swath width of 170 feet (50 m), corresponding to 500 feet of boom deployed with a gap ratio (i.e., the ratio of the swath width to total boom length) of 1:3 unless greater boom lengths can be demonstrated and documented through drills, exercises, and field experimentation.

3.6 Slick encounter speeds

A default encounter speed of 0.7 knots is proposed, which is the speed at which most containment systems begin to lose oil due to entrainment. However, there are several recent boom designs that offer containment at speeds of 3 knots and greater. If a specified system utilizes such a system, and its performance at speeds greater than 0.7 knots has been documented in field or tank tests, then an improved encounter speed can be used.

3.7 Burn rates

A methodology for estimating burn rates is provided in a draft ASTM standard (currently listed as a work item): WK37324 Guide for estimating the volume of oil consumed in an in-situ burn.

The guide describes a methodology for estimating the effectiveness of an in-situ burn, with burn effectiveness reported as total volume burned and/or burn efficiency (i.e., volume burned of that available.

The evaluation approach is based on the fact that, for most oils and under most conditions, oil slicks burn at a rate of between 2 and 4 mm/min (0.08 and 0.16 in/min). By accurately observing the total area of an in-situ burn and the total duration of the burn it is possible to estimate the volume of oil consumed in the burn.

The standard provides:

- consensus estimates on the burn rate for a variety of crude and refined oils;
- a procedure for estimating burn area within a boomed configuration, and;
- a procedure for combining these two factors to produce an estimate of burn volume.

3.8 Degradation of boom as a result of heat exposure

Several models of fire-resistant boom were used extensively used in response to the Macondo spill, with approximately 400 burns conducted (Mabile 2010). There is little documentation on the longevity of the specific fire booms used in the response, but an overall average usage, for these three booms that were used successfully, was approximately five burns per system. The longest recorded burn with this boom was approximately 12 hours.

3.9 Identify the range of operating conditions that in situ burning can be used (sea state, winds, ignition window of opportunity for various oil types);

Temperature, wind, currents, and waves promote various physical and chemical changes to a spill that can make the oil difficult or impossible to ignite. High temperatures and winds result in the rapid loss of volatile components and reduction of film thickness. High wind and sea states can increase the rate of emulsion formation and the rate of heat transfer through the slick, both of which reduce ignitability.

Although there is little data on the effects of sea state on in-situ burning, experience exists suggests that the sea-state limit for effective burning is from 1 to 1.2 metres (3.3 to 4 feet) significant wave height or less. Also, if the fire-resistant boom fails to hold oil in during any of these sea state conditions, burning would not be practical. In pack ice conditions, the presence of ice floes tends to dampen waves, possibly enhancing the burning of oil in open areas between such floes.

Winds of approximately 30 to 40 km/h (15 to 20 knots) are considered to be the upper limit for ignition of oil pools in the absence of waves. These constraints reflect both the current state-of-the-art in proven ignition and fire-resistant booms systems, as well as the environmental conditions under which most oils will be quickly weathered (i.e., emulsified) beyond a combustible state in open water. Again, the presence of pack ice may greatly extend the window-of-opportunity for igniting spilled oil in-situ. Oil encapsulated in ice will not weather significantly, until it is released on to the surface of the ice the following spring.

Another important environmental factor favoring burning is good visibility. For a safe and effective burn to take place with fire-resistant boom or in pack ice with, or without, herders it should be possible to see:

- the oil to be collected,
- the vessels towing the fire-resistant booms, and
- the proximity of the intended burn location relative to the spill source, other vessels in the area, and other potentially ignitable slicks.

As a guide, Visual Flight Rules (VFR) flying conditions (greater than 3 miles (4 km) visibility and a minimum 500 ft (300 m) ceiling) could be used. If helicopters are to be used, VFR flying conditions must exist both at the site and at the helicopter base. If burning is to be conducted at a remote, fixed, continuous source of spilled oil (e.g., an offshore blowout), it may be feasible to burn spilled oil safely at or near the source during limited visibility conditions (e.g., less than VFR flying conditions, dusk, dawn, etc.).

The minimum and ideal conditions for controlled in-situ burning are summarized in Table 3 (Mabile 2013).

Table 3: Minimum and ideal conditions for controlled in-situ burning

Consideration	Ideal condition	Minimum condition
Oil thickness	• > 2 mm (0.08 in) for most fresh oils • 2 to 5 mm (0.08 to 0.2 in) for weathered crudes	• 1 to 3 mm (0.04 to 0.12 in) for "fresh" crude oil, • 3 to 5 mm (0.12 to 0.2 in) for diesel and weathered crude, • 5 to 10 mm (0.12 to 0.24 in) for weathered crude, diesel, Bunker C fuel oil)
Emulsification	0 to 12.5% water	• < 25% water for crude oils that form stable emulsions • < 50% for light crudes that form unstable emulsions
Weathering	20 to 35% evaporated	35% evaporated
Waves	< 1 m (< 3 ft)	< 1.5 m (< 5 ft)
Wind	< 2 to 10 m/s (4 to 20 knots)	< 10 m/s (20 knots); may be up to 12 m/s (23 knots) for large burns
Current	< 0.75 knots, perpendicular to a boom	< 0.5 m/sec (< 1 knot)
Oil density	< 0.864 g/mL (SG 0.86)	< 1.0 g/mL (SG 1.0)

Some fire-resistant booms are heavy and difficult to handle, but are also durable and able to survive burning in an offshore marine environment for long periods. These are typically metal booms. Others are lighter and easier to handle and deploy but are not designed for long-term deployment offshore or long-term exposure to fire. These usually employ fire-resistant, mineral-based fabric and ceramics and in some cases include a water-cooled outer membrane. It is important for planners and field personnel to anticipate the full range of constraints that may be imposed on the burning operation because of a boom's particular weight and handling requirements. With proper training, experience has shown that fire-resistant booms can be deployed quickly and used in the same manner as most comparably sized conventional booms.

Minimum dimensions and performance requirements for fire-resistant boom are specified in section 3.12.

3.10.2 Ignition source

There are several commercially-available devices for igniting spilled oil. Of these, the Heli-torch is one of the most cost-effective, reliable and flexible systems for the aerial application mode. The Heli-torch provides an off-the-shelf ignition system that has been used for many years by forest fire fighting organizations in different parts of the world. Because of the quantity of gelled fuel that can be carried (typically from 100 to 1000 L, 25 to 250 gallons), it is possible to release ignition fluid (gelled fuel) as individual ignition points in short bursts or in a continuous mode for up to several minutes. Gelled fuel ignition points, typically “fist-sized”, fall to the surface and burn for several minutes. With the Heli-torch operated from a hovering position (at altitudes of 8 to 80 m [20 to 200 feet] or more), it is possible to create very large initial ignition areas in a continuous mode for difficult-to-ignite weathered or partially emulsified oil layers.

In spill situations where a helicopter's staging area is distant from the proposed burn region, such as in the case of igniting oil on many melt pools from an over-winter spill under pack ice, it may be advisable to locate nearby temporary landing sites where the helicopter could set down between ignitions. A single drum of gelled fuel within the Heli-torch would normally be large enough to support the ignition of numerous individual burns. During an extensive ongoing burn operation it may be helpful to move backup Heli-torches, fuel, mixing facilities and gelling agent to forward landing sites in order to avoid delays because of long transit distances to the primary staging location. Ships or offshore exploration/production platforms with appropriate heli-decks may also be used, if the transport and mixing of the gasoline-based Heli-torch fuel is allowed onboard. One example of this approach would be a large, appropriately-classed icebreaker located in pack ice to support springtime melt pool ignition operations.

A variety of simple and ad-hoc ignition devices have been used for marine and land spills, including propane/butane torches, weed burners, and sorbent pads soaked in fuel. For example, test burn performed at the *Exxon Valdez* was ignited using a floating bag of gelled gasoline. During the response to the Macondo incident, ad-hoc igniters were initially made by filling plastic containers with a mixture of diesel fuel and gelling agent, and securing a marine flare to the outside. Similar ignition devices have been made using gelled gasoline contained in sealable plastic bags (Potter 2010).

3.10.3 Vessel support

The most successful burn task groups include four vessels:

- An offshore support vessel ("OSV"), providing accommodations for the burning crew, crane services, and working deck space for boom deployment, retrieval, and maintenance/repair.
- Boom "towboats" – Deployed in pairs for pair-trawling, or "U-boom sweeping" operations to concentrate the oil for burning. (Fishing vessels, particularly trawlers or draggers were particularly valuable for this duty in the Gulf of Mexico (GOM)).
- "Igniter boat" - Small, fast, low-freeboard boats to deliver igniter packages and carry out modest in-water boom repairs.

It is important that all vessels used during offshore burning operations have sufficient power to pull the size and length of fire-resistant boom being considered and be suitable for the ice conditions prevalent. Vessels with twin variable-pitch propellers are generally preferred; and powers in the 100 to 150 kW (150 to 200 hp) range are generally sufficient for boom tow boats. Large vessels (e.g., 45- to 60-m [150- to 200-foot] supply vessels) make ideal platforms for large containment booms and recovery systems, although such vessels are often over-powered for the needs of pulling boom. Experience has shown that small towing boats in the 8- to 12-metre (25- to 35-foot) range are usually much better for controlling a simple track-down and collection operation, particularly when towing speeds need to be maintained for extended periods at 0.5 m/s (1 knot) and less. This size of towing boat can often be transported to the burn area with a larger vessel and deployed and recovered from the larger vessel. Regardless of the size of vessel selected, it is important that its propulsion system permit the vessel to maintain steerage at speeds in the 0.5 m/s (1 knot) and lower range. Small fishing vessels with trawling gear were found to be very effective at low-speed towing for sustained periods during the Macondo response.

Vessels used for the towing of fire-resistant boom need to be equipped with properly positioned tow-posts or bitts and adequate lengths of tow line (typically 100 m to 200 m, 300 to 600 feet). The tow lines need to be strong enough to accommodate the maximum drag forces that would likely be experienced during the towing of boom in open-water conditions. For example, working with an anticipated maximum drag force of about 11,000 to 13,000 Newtons (N) (2500 to 3000 lbs) and a static system safety factor (SSSF) of 7, a polypropylene tow line with a 33 mm (1-5/16”) diameter would be required. A similar tension strength (i.e., about 93,000 N or 21,000 lbs) could be achieved with the use of a 27 mm (1-1/16 inch) nylon line or a 25 mm (1- inch) polyester line. Buoyant lines are preferred to avoid entanglement with vessel propellers. Tow loads for fire booms operating in drift ice will be approximately twice those in open water.

Vessels should also have space to carry fire-resistant booms to the burn site and space to deploy them. The size and weight of the boom must conform to the deck space and safe load-carrying capacity of each vessel. When the boom-towing boats are too small to carry the entire boom on deck, the fire-resistant booms may be pulled in a straight-line tow (typically at speeds of about 9 to 18 km/h [5 to 10 knots]), or the boom can be transported to the oil collection area with the aid of an additional vessel or barge. In some cases, helicopters may be used to transport short lengths of fire boom from shore or from a vessel to the spill site. All vessels should be equipped with explosimeters.

3.10.4 Aerial surveillance

Aerial surveillance using airplanes or helicopters will be highly important in providing an ongoing update on the status of the spill source and the resultant oil slicks. As with mechanical containment and recovery operations, spotter aircraft can provide guidance for surface vessels involved with the location and removal of oil. Aerial observers can keep boom towing vessels appraised of their location relative to fresh, thick oil layers and they can ensure that burns are conducted to minimize interference with other response activities. The maintenance of an aerial surveillance programme will also permit the early detection of any sudden shifts in wind direction (and resulting smoke plume trajectories), allowing for the warning of any downwind operations or population centers.

3.10.5 Trained personnel

Individuals involved with the planning and implementation of controlled burning of oil at sea should be trained in both the theory and hands-on aspects of contained in-situ burning. The amount and focus of the training should reflect the job and level of responsibility assigned to each member of the burn team. Areas of instruction should include:

- Response organization and management such as an incident command system (ICS), including specific job assignments;
- Government regulations and permitting procedures;
- Communications (specific to command and control interfacing, and vessels and aircraft involved with the burning operations);
- Strategies and priorities for response, including procedures for coordinating with aerial support/spotting operations and other spill control activities;
- Basic combustion theory and fire prevention and control techniques;
- Safe equipment handling procedures (fire-resistant booms, igniters, vessels, etc.);
- Equipment and procedures for the possible recovery and storage of burn residue;
- Personal protection equipment and first aid;
- Backup response strategies (i.e., identification of potential emergency conditions and appropriate response procedures);
- Avoidance and minimization of environmental impacts; and,
- Procedures for documenting the size and duration of each burn.

It is important that trained personnel be available on each vessel and aircraft used for the burning operation. Individuals assigned to field-operation positions should be familiar with the deployment and use of fire-resistant boom, aerial and surface ignition systems, and other equipment necessary to carry out a safe and effective burn. Response personnel training should satisfy all Occupational Safety and Health Administration (OSHA) regulations (both federal and state) and they should have received appropriate levels of training in the Hazardous Waste Operations and Emergency Response (HAZWOPER) training programm per 29 CFR 1910.120. (Note: As a result of the extensive use of in-situ burning during the Macondo response, there is an ongoing API-sponsored initiative to identify the training and qualification requirements for ISB responders; API Technical Report 1253-*Selection and Training Guidleings for In Situ Burning Personnel* should be available in 2016.)

3.11 Identify a methodology to calculate a burn potential based on encounter rate and the parameters selected for the components of a "burn system"

Some of the key elements described above will be essentially checklist itemsto determine if a proposed system meets the minimum requirements.

Elements relating to encounter rate, encounter speed, and burn rate will be combined in a spreadsheet configuration.

3.12 Establish minimum performance requirements for the use of firebooms

Minimum physical specifications for fire-resistant boom are contained in ASTM F2152-07(2013) Standard Guide for In-Situ Burning of Spilled Oil: Fire-Resistant Boom (Table 4).

Table 4: Minimum Design Values for Fire-Resistant Boom

Boom Property	Calm Water[A]	Calm Water Current[A]	Protected Water[A]	Open Water[A]
Freeboard prior to burn, mm	120	130	260	530
Freeboard following burn, mm	60	70	130	270
Draft, mm	150	160	330	660
Gross buoyancy-to-weight ratio prior to burn	3:1	3:1	3:1	3:1
Gross buoyancy-to-weight ratio following burn	1.5:1	1.5:1	1.5:1	1.5:1
Tensile strength, N per mm of boom draft[B]	57	140	64	72
Tear strength, N	450	450	450	450

A. Water body types defined in ASTM Practice F 625.

B. Tensile strength measured by ASTM Test Methods F 1093.

ASTM F2152 contains other minimum equipment performance characteristics, reproduced below. In particular, the requirement that a boom be subjected to, and survive, three 1-hour burns was proved to be a good indicator of fire boom performance in the Macondo response. The three booms that were used most extensively during Macondo had all met this ASTM standard, while several booms that did not meet the ASTM standard were quickly found to be un-usable in Macondo.

5.1.1 Minimum performance characteristics are grouped under three headings: Operability, Oil Containment; and Fire- Resistance. All minimum performance characteristics listed here shall be achieved before a boom is considered to meet the requirements of this guide.

5.1.2 The fire-resistant boom shall withstand oil fires and contain oil in various conditions that include both calm water and waves with a significant wave height of up to 1 m (3 ft) and a period of 3 to 4 seconds.

5.1.3 For booms intended for use in salt water or brackish water, the boom shall be tested in water that has a salinity of 15 o/oo (parts per thousand) or greater. For booms that rely on wicking, the salinity shall be 33 o/oo or greater. For actively-cooled booms, the water in which the boom is tested may be 15 o/oo if the water supplied to the boom (from a separate supply) has a salinity of 33 o/oo or greater.

5.2 Operability Characteristics:

5.2.1 The fire-resistant boom shall meet the minimum physical dimensions and strength parameters as for conventional oil containment booms, except for the buoyancy-to-weight ratio. These parameters are listed in ASTM Guide F 1523 and summarized in Table 3.

5.2.2 Total Tensile Strength—Prior to exposure to an in-situ burn, the fire-resistant boom shall meet the minimum total strength for the various water body classifications listed in Table 4.

5.2.3 Total tensile strength for fire-resistant booms may decrease after each burn exposure. In any case, the boom shall retain sufficient strength following a burn to retain burn residue and any unburned oil and to allow the salvage or disposal of the boom.

5.2.4 Corrosion Resistance—Fire-resistant oil spill containment booms (and ancillary systems, if applicable) shall be manufactured of components that do not degrade significantly and that maintain fire resistance characteristics while exposed to typical marine environmental conditions.

5.2.5 Extreme Temperature Properties—The fire-resistant boom and any ancillary equipment shall not be adversely affected by use or storage at temperatures within the range of -40 to 40°C (-40 to 100°F).

5.2.6 Fabric Tests—Fabrics and components shall meet the applicable test methods for fabrics used in spill control barriers and temporary storage devices in accordance with ASTM Test Methods F 715.

5.2.7 Hazardous Waste—If the boom’s materials of manufacture include any hazardous materials, the appropriate Material Safety Data Sheet and exposure limits shall be provided by the manufacturer. The fire-resistant boom system shall not create or add to the hazardous waste pollution, nor shall it have any special disposal requirements beyond that typically required of oil spill booms.

5.2.8 End Connectors—The fire-resistant boom section interconnections shall meet boom fire tolerance requirements.

5.2.9 Documentation—Documentation shall be provided by the manufacturer addressing storage, handling, maintenance, health and safety, test results, and recommended repair procedures.

5.3 Oil Containment Characteristics:

5.3.1 Prior to exposure to an oil fire, the fire-resistant boom shall display similar oil containment characteristics expected of conventional oil spill containment booms.

5.4 Fire-Resistance Characteristics:

5.4.1 The fire-resistant boom shall contain oil and survive in heat fluxes equivalent to an in-situ burn of diesel with a minimum diameter of 4.5 m (15 ft), for a total of three 1-hour burn cycles, with a minimum 1 hour cool down between cycles.

5.5 Additional Requirements for Actively–Cooled Booms:

5.5.1 Additional fire-resistance testing for actively-cooled booms is specified in 6.5.2 to confirm the adequacy of backup systems for coolant supply. To fulfill the additional test requirement, it is recommended that actively-cooled booms have the following features:

5.5.1.1 Backup coolant supply system,

5.5.1.2 Flowmeter or indicator on each coolant supply to monitor the flow, and 5.5.1.3 Capability to switch to the backup coolant supply in the event of failure of the primary supply.

5.5.2 The manufacturer shall specify the required minimum flowrate and corresponding pressure drop per unit length (of hose and boom) required to adequately cool the boom.

5.5.3 Previous testing has identified the clogging of nozzles and small orifices as a potential problem with actively-cooled booms. To negate this as a potential problem, it is recommended that the coolant supply be filtered or that adequate redundancy in coolant supply be provided, or both.

Appendix A:

Proposed Standard Guide for Estimating In-Situ Burning System Effectiveness

1. Scope

1.1 This guide covers the key factors to consider in estimating the effectiveness of in-situ systems that may be used to assist in the control of oil spills on water.

1.2 The purpose of this guide is to provide the user with information on assessing the effective use of in-situ burning equipment. It is intended for use by those involved in planning for and responding to oil spills.

1.3 Sections of this guide describe calculation procedures for estimating in-situ burning system effectiveness. It should be understood that any such calculations cannot be expected to predict system performance, but are intended to provide a common basis for comparing system performance.

1.4 One of the main reasons that the calculation procedures cannot be used to predict system performance is that the analysis is sensitive to assumptions made on the properties of the oil slick, and particularly the changes in slick thickness and emulsification. It is emphasized that the purpose of this guide is not to provide a standard method for estimating slick property changes, but rather to provide a standard guide for using that information in comparing system performance.

2. Referenced Documents

ASTM F1780 Standard Guide for Estimating Oil Spill Recovery System Effectiveness

3. Terminology

Mobilization time: the time interval between the notification of a spill occurring and the activation of response resources.

Transit time: the time required to deliver response resources to the area of response operations.

Response time: the time interval between the spill incident and the start of cleanup operations. (ASTM F1780) *(Note: Response time is equivalent to Mobilization time plus Transit time.)*

Oil slick encounter rate: the volume of oil slick per unit time actively encountered by the in-situ burning system and therefore available for burning (m^3/h). (*adapted from ASTM F1780*)In-situ burning system: a combination of devices that operate together to burn oil in-situ; the system would include some or all of the following components: (1) surveillance aircraft, (2) fire-resistant containment boom, (3) support vessels to deploy and operate the boom, (4) an ignition source, (5) trained personnel. (*adapted from F1780*)

In-situ burning system effectiveness: the volume of oil that is removed from the environment by a given in-situ burning system in a given period.

4. Summary of Guide

4.1 In evaluating the effectiveness of in-situ burning (ISB) systems used in response to oil spills, many factors need to be considered. The objective of this guide is to describe a range of factors that must be considered in estimating recovery system effectiveness.

4.2 In order to evaluate an ISB system, there are two general types of information required, a set of information to describe the spill scenario against which the system will be measured, and a set of information to describe the performance characteristics of the ISB system.

4.3 Information on the spill is required to adequately define the problem and thereby provide a focus for the evaluation process. The spill should be defined in sufficient detail as to allow an unambiguous interpretation of its behavior in terms of the operating parameters of the countermeasures system. For certain purposes it may be desirable to develop a set of standard spill scenarios against which ISB system effectiveness would be measured in a quantifiable manner.

4.4 The performance characteristics must be identified for the ISB system and its various components. In general, the information requirements will include the rates or capacities, or both, the operating limitations, and the support requirements.

4.5 This guide covers equipment-related factors that will affect recovery-system effectiveness. Additional important factors that are not covered in this guide but should be considered as being critical to the success of a spill response include: contingency planning; communications plans; government approvals; logistics of supporting manpower and equipment in the field; and training and exercising of manpower.

5. Spill-related Information

5.1 Spill Type:

5.1.1 Response strategies will depend to some extent on the type of spill. The spill scenario should be defined as to whether it is an instantaneous or continuous release, whether or not the spill has ceased flowing, and whether the spill is contained or uncontained.

5.2 Oil Slick Properties The following oil slick properties must be specified for the spill scenario. As some of these properties may vary with time, it may be desirable to use computer-based behavior models to produce spill property information for the time period of interest. For certain applications it may be useful to produce standard sets of spill property information that describe spills of interest as a function of time.

5.2.1 Spill Volume The total volume of oil spilled should be specified (m^3). For spills that have not ceased, a spill rate (m^3/h) should also be specified.

5.2.2 Spill Area The total spill area must be estimated in order to calculate estimates of slick thickness. For uncontained spills, the total spill area will increase over time; estimates can be made using computer-based behavior models. Alternatively, a simplified spreading curve can be used for first-order estimates.

5.2.3 Slick Thickness Slick thickness is used in subsequent calculations of system encounter rate. Slick thickness is defined as the overall average thickness of the slick, and is estimated by dividing the spill volume by the total spill area at any given time. For this calculation, spill volume should take into account losses from the slick due to evaporation and natural dispersion, and increases to the slick volume due to emulsification. For uncontained spills, natural spreading forces will cause the slick thickness to decline steadily during recovery operations, and may result in a discontinuous slick composed of windows and patches separated by sheen or open water, or both. These factors should be considered in estimating an overall average slick thickness.

5.2.4 Emulsification Emulsification is important as a spill process as it may limit the ability to successfully ignite and burn the oil. Many crude oils and refined products will tend to emulsify over the life of the spill depending on the properties of the oil and the level of wave energy in the spill environment. The degree of emulsification should be specified as the emulsified water content expressed as a percentage.

5.2.5.1 It is recognized that emulsification rates for oil spilled in the marine environment will vary greatly depending on the oil properties, spill size, sea conditions, and temperature. As noted in 1.4, it is not the intent of this guide to provide standard rates of emulsification for a variety of oil products and environmental conditions. For the purposes of comparing system performance, the data in Table 1 is provided as an example of emulsification data for crude oil over a period of several days. Users of this guide are encouraged to use alternative data that suits their particular oils and environmental conditions.

5.3 Spill Environment:

5.3.1 Temperature— Water temperature is important as a parameter for estimating oil slick properties as well as the rate of change of those properties due to weathering and emulsification. (It is assumed that the temperature of the oil slick is the same as the water on which the oil is floating.) Water temperature is defined as the temperature of the upper surface layer and should be specified as °C.

5.3.2 Wind/Waves The wind and wave environment is important to the analysis for two reasons; first, as a parameter in estimating the behavior changes of the oil slick, and second, as a limiting factor for burning operations. For the first purpose, average wind speeds (km/h) should be specified. For the purpose of establishing criteria for limiting burning operations, exceedance statistics (significant wave height) should be specified for the spill location. Exceedance criteria should be expressed as the percentage of time that conditions will allow recovery operations with reference to the equipment selected for the response and the environmental criteria listed in ASTM Practice F 625. For example, for spills in open water, wave exceedance data should be specified as the percentage of time that waves are less than or equal to 2 m, which would represent the percentage of time that equipment specified for open water use would be applicable.

5.3.3 Current The presence of water currents may influence the selection of response strategies for a spill scenario, and may lead to a reduction in containment effectiveness in certain applications. The water currents, in m/s, should be specified for a given environment, with due regard to any local variations.

5.3.4 Visibility Due to concerns with worker safety in poor visibility, as well as the inefficiencies related to the monitoring, tracking, and containment of oil slicks during periods of poor visibility, it is assumed in general that burning operations are only possible when there is daylight and visibility of greater than 500 m (0.25 n.miles). Both of these factors should be expressed as the percentage of time that conditions exist that would allow effective operations.

5.3.4.1 It may be possible to effectively operate during periods of darkness and poor visibility if the recovery system includes adequate lighting equipment, remote sensing systems for assisting monitoring and containment efforts, or highly accurate navigation systems, or combination thereof. This may be particularly applicable to spills in nearshore and protected waters. In such cases a more liberal criteria for visibility limitations could be specified.

5.3.5 Summary of Environmental Applicability Factors The wave exceedance, daylight, and visibility factors can be combined to produce an overall applicability factor that would represent the percentage of time that a given recovery system could be effectively used for a given spill scenario. For example, for an environment that has waves less than 2 m for 80 % of the time, receives 14 h of daylight, and has visibility greater than 500 m for 95 % of the time (note: all figures should be specified for the time of year of interest), the environmental applicability would be estimated as: (0.80) × (14/24) × (0.95) = 44 %.

5.4 Spill Location:

5.4.1 Spill location should be specified with respect to distance of response bases, in order to estimate transit times for the recovery systems, and with respect to shoreline, in order to estimate the time available to respond prior to shoreline oiling.

6. ISB System Information

6.1 Containment System Operating Factors:

6.1.1 Encounter Rate The encounter rate of the recovery system is a prime consideration in evaluating performance. The encounter rate is simply the rate (m3/h) at which the system encounters the oil slick. The encounter rate includes three components: sweep width, encounter speed, and oil slick thickness.

6.1.1.1 The sweep width (or swath) is the width intercepted by a boom in collection mode, and is calculated by multiplying the boom length by the gap ratio. Where the gap ratio is not specified, a value of 1/3 should be used.

6.1.1.2 The encounter speed is the tow or current speed relative to the containment system. If not specified, a maximum encounter speed of 0.5 m/s (1 knot) should be used.

6.1.1.3 Encounter rate can be calculated as the product of these three factors, taking into account consistency of units. As well, simple nomograms (Fig. 2) can be used to estimate encounter rates for a range of conditions.

6.1.2 Operating Limitations—Containment equipment must be specified with regard to the environmental conditions of the given spill scenario. Guidance for selecting booms can be taken from Guide F 1523, which lists minimum requirements for boom dimensions and strength properties for calm, protected, and open bodies of water. Other limitations on the specified boom, such as minimum water depths and maximum tow speeds should also be listed.

6.1.2.1 The applicability of a boom to a given spill scenario should be considered as a constraint to containment operations. For example, a boom designated for calm water use (in accordance with Guide F 1523) will be satisfactory for containment operations in waves up to 0.3 m (1 ft). If the wave climate for a given area is such that 0.3 m waves are exceeded 25 % of the time then the boom could be considered to be applicable 75 % of the time.

6.1.2.2 Encounter speed is included as a factor in calculating the encounter rate. For most booms the maximum encounter speed will be in the range of 0.35 to 0.5 m/s (0.7 to 1 knot). It is recognized that certain containment systems have been designed to operate at higher encounter speeds: greater speeds than those noted above may be used if test data is available to support the selected encounter speed. For most booms, encounter speeds greater than 0.5 m/s should be used only with an accompanying reduction in the system's throughput efficiency to account for losses from the containment system.

6.1.3 Support Requirements Support requirements for the listed containment equipment should be specified. Support requirements could include: transportation to deliver the boom to the spill site; equipment such as cranes or winches required to deploy, tow, and retrieve the boom; boom tackle such as tow lines, marker buoys, anchors, connectors; power or air requirements, or both, for boom deployment, operation, and retrieval; adequate manpower for deployment and retrieval; and vessels with adequate deck space for the required equipment, as well as adequate power and maneuverability for the specific situation. Any limitations on the specified support equipment should be specified; these could include: sea-state limits for vessel operation; draft limits on the vessels; minimum and maximum transit and tow speeds; and limits on vessel operation with respect to distance of shore.

6.2 ISB System Operating Factors:

6.2.1 Fire-resistant boom lengths Based on extensive experience in the response to the Macondo blowout, 500-foot (150-metre) lengths of is recommended as a default maximum boom length unless greater boom lengths can be demonstrated and documented. Based on this, a default swath width of 170 feet (50 m), corresponding to 500 feet of boom deployed with a gap ratio of 1:3 unless greater boom lengths can be demonstrated and documented through drills, exercises, and field experimentation.

6.2.2 Burn rates A methodology for estimating burn rates is provided in a draft ASTM standard (currently listed as a work item): WK37324 Guide for estimating the volume of oil consumed in an in-situ burn. The evaluation approach is based on the fact that, for most oils and under most conditions, oil slicks burn at a rate of between 2 and 4 mm/min. By accurately observing the total area of an in-situ burn and the total duration of the burn it is possible to estimate the volume of oil consumed in the burn.

6.2.3 Degradation of boom as a result of heat exposure Several models of fire-resistant boom were used extensively used in response to the Macondo spill, with approximately 400 burns conducted (Mabile 2010). There is little documentation on the longevity of the specific fire booms used in the response, but an overall average usage, for these three booms that were used successfully, was approximately five burns per system. The longest recorded burn with this boom was approximately 12 hours.

6.2.4 3 Ignition source There are several commercially-available devices for igniting spilled oil. Of these, the Heli-torch is one of the most cost-effective, reliable and flexible systems for the aerial application mode. The Heli-torch provides an off-the-shelf ignition system that has been used for many years by forest fire fighting organizations in different parts of the world. Because of the quantity of gelled fuel that can be carried (typically from 100 to 1000 L), it is possible to release ignition fluid (gelled fuel) as individual ignition points in short bursts or in a continuous mode for up to several minutes. Gelled fuel ignition points, typically “fist-sized”, fall to the surface and burn for several minutes. With the Heli-torch operated from a hovering position (at altitudes of 8 to 80 m or more), it is possible to create very large initial ignition areas in a continuous mode for difficult-to-ignite weathered or partially emulsified oil layers.

A variety of simple and ad-hoc ignition devices have been used for marine and land spills, including propane/butane torches, weed burners, and sorbent pads soaked in fuel. For example, test burn performed at the Exxon Valdez was ignited using a floating bag of gelled gasoline. During the response to the Macondo incident, ad-hoc igniters were initially made by filling plastic containers with a mixture of diesel fuel and gelling agent, and securing a marine flare to the outside. Similar ignition devices have been made using gelled gasoline contained in sealable plastic bags (Potter 2010).

6.3 Vessel support

The most successful burn task groups include four vessels:

- An offshore support vessel (“OSV”), providing accommodations for the burning crew, crane services, and working deck space for boom deployment, retrieval, and maintenance/repair.
- Boom “towboats” – Deployed in pairs for pair-trawling, or “U-boom sweeping” operations to concentrate the oil for burning. (Fishing vessels, particularly trawlers or draggers were particularly valuable for this duty in the GOM)
- “Igniter boat” - Small, fast, low-freeboard boats to deliver igniter packages and carry out modest in-water boom repairs.

It is important that all vessels used during offshore burning operations have sufficient power to pull the size and length of fire-resistant boom being considered and be suitable for the ice conditions prevalent. Vessels with twin variable-pitch propellers are generally preferred; and powers in the 100 to 150 kW (150 to 200 hp) range are generally sufficient for boom tow boats. Large vessels (e.g., 45- to 60-m supply vessels) make ideal platforms for large containment booms and recovery systems, although such vessels are often over-powered for the needs of pulling boom. Experience has shown that small towing boats in the 8 to 12 metre range are usually much better for controlling a simple track-down and collection operation, particularly when towing speeds need to be maintained for extended periods at 0.5 m/s (1 knot) and less. This size of towing boat can often be transported to the burn area with a larger vessel and deployed and recovered from the larger vessel. Regardless of the size of vessel selected, it is important that its propulsion system permit the vessel to maintain steerage at speeds in the 0.5 m/s (1 knot) and lower range. Small fishing vessels with trawling gear were found to be very effective at low-speed towing for sustained periods during the Macondo response.

Vessels used for the towing of fire-resistant boom need to be equipped with properly positioned tow-posts or bitts and adequate lengths of tow line (typically 100 m to 200 m). The tow lines need to be strong enough to accommodate the maximum drag forces that would likely be experienced during the towing of boom in open-water conditions. For example, working with an anticipated maximum drag force of about 11,000 to

13,000 Newtons (N) (2500 to 3000 lbs) and a safety factor of 7, a polypropylene tow line with a 33 mm (1-5/16”) diameter would be required. A similar tension strength (i.e., about 93,000 N or 21,000 lbs) could be achieved with the use of a 27 mm (1-1/16 inch) nylon line or a 25 mm (I inch) polyester line. Buoyant lines are preferred to avoid entanglement with vessel propellers. Tow loads for fire booms operating in drift ice will be approximately twice those in open water.

Vessels should also have space to carry fire-resistant booms to the burn site and space to deploy them. The size and weight of the boom must conform to the deck space and safe load-carrying capacity of each vessel. When the boom-towing boats are too small to carry the entire boom on deck, the fire-resistant booms may be pulled in a straight-line tow (typically at speeds of about 9 to 18 km/h [5 to 10 knots]), or the boom can be transported to the oil collection area with the aid of an additional vessel or barge. In some cases, helicopters may be used to transport short lengths of fire boom from shore or from a vessel to the spill site. All vessels should be equipped with explosimeters.

6.3.2 Aerial surveillance Aerial surveillance using airplanes or helicopters will be highly important in providing an ongoing update on the status of the spill source and the resultant oil slicks. As with mechanical containment and recovery operations, spotter aircraft can provide guidance for surface vessels involved with the location and removal of oil. Aerial observers can keep boom towing vessels appraised of their location relative to fresh, thick oil layers and they can ensure that burns are conducted to minimize interference with other response activities. The maintenance of an aerial surveillance programme will also permit the early detection of any sudden shifts in wind direction (and resulting smoke plume trajectories), allowing for the warning of any downwind operations or population centers.

6.3.3 Trained personnel Individuals involved with the planning and implementation of controlled burning of oil at sea should be trained in both the theory and hands-on aspects of contained in-situ burning. The amount and focus of the training should reflect the job and level of responsibility assigned to each member of the burn team. Areas of instruction should include:

- Response organization and management, including specific job assignments;
- Government regulations and permitting procedures;
- Communications (specific to command and control interfacing, and vessels and aircraft involved with the burning operations);

- Strategies and priorities for response, including procedures for coordinating with aerial support/spotting operations and other spill control activities;
- Basic combustion theory and fire prevention and control techniques;
- Safe equipment handling procedures (fire-resistant booms, igniters, vessels, etc.);
- Equipment and procedures for the possible recovery and storage of burn residue;
- Personal protection equipment and first aid;
- Backup response strategies (i.e., identification of potential emergency conditions and appropriate response procedures);
- Avoidance and minimization of environmental impacts; and,
- Procedures for documenting the size and duration of each burn.

It is important that trained personnel be available on each vessel and aircraft used for the burning operation. Individuals assigned to field-operation positions should be familiar with the deployment and use of fire-resistant boom, aerial and surface ignition systems, and other equipment necessary to carry out a safe and effective burn. Response personnel training should satisfy all Occupational Safety and Health Administration (OSHA) regulations (both federal and state) and they should have received appropriate levels of training in the Hazardous Waste Operations and Emergency Response (HAZWOPER) training programme. (Note: As a result of the extensive use of in-situ burning during the Macondo response, there is an ongoing API-sponsored initiative to identify the training and qualification requirements for ISB responders; the results should be available in 2013.)

6.4.1 Response Time— The response time is defined as the time interval between the spill incident and the start of recovery operations. A response time should be estimated for the scenario taking into account an adequate time for the mobilization of recovery resources (that is, time to notify response teams and assemble the required equipment) as well as estimating a transit time of resources from the response base to the scene of the spill. In estimating transit times, unless otherwise justified, transit speeds of 10 km/h (5 knots) by water, 55 km/h (35 mph) by land, and 185 km/h (100 knots) by air should be assumed.

Appendix B: Discussion on Default Slick Thicknesses

Importance of Oil Thickness

A value for the thickness of encountered oil is key to estimating how much oil may be burned in an ISB system or recovered by a skimming system. In calculating an encounter rate, the three main variables are:

- Slick thickness;
- Swath width (a function of boom length and the gap ratio of the configuration; and
- Encounter speed, or towing speed

Of these, the most highly variable factor is the slick thickness. For a given spill, the slick thickness may vary by an order of magnitude or more over the course of a few days. For example, in a comprehensive study on revising the encounter rate to be used in EDRC calculations, Genwest provided a summary of several well-known oil spill behavior models (Figure B-1).

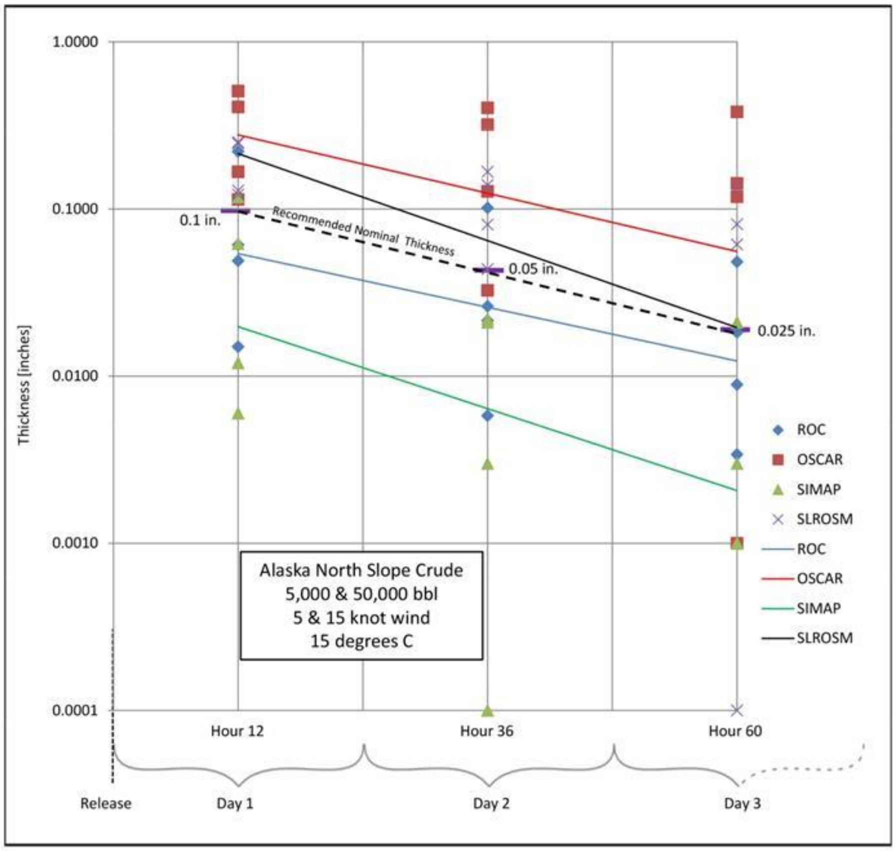

Figure B-1: Summary of four spill models (Genwest report)

The models used for Figure B-1 were:

- the Genwest Response Options Calculator;
- the Applied Science Associates (SIMAP) model;
- the SINTEF OSCAR model; and
- the SL Ross Oil Spill Model - SLROSM

Data for Alaska North Slope Crude (ANS) was used for the comparison because its properties are in the databases of all the models. Simulated releases of 5,000 and 50,000 barrels at wind speeds of 5 and 15 knots were modeled. All runs were at 15°C.

Regardless of the specific model selected the results in Figure 1 show a decline in slick thickness, over the first three days of a spill, by a factor of about 1:10 or more. The authors of the study selected a nominal thickness of 0.1, 0.05, and, 0.025 inches to represent the slick thickness on Days 1, 2, and 3 of a spill. This seems reasonable as an approximation for instantaneous, or “batch” spills, but note that there is a wide divergence in the modeled results, as shown in Figure 1, which is depicted in a logarithmic scale. For the same 50,000 bbl spill, modeled thicknesses at 12 hours range from approximately 0.01 inches to approximately 0.6 inches, or by a factor of 60. The assumed thicknesses are summarized in Table 1.

Table B-1: Recommended slick thickness, Genwest report (page 34)

Time from start of spill, h	Slick thickness, inches	Slick thickness, mm
12	0.1	2.5
36	0.05	1.3
60	0.025	0.63

However, for blowout spills, there was no modeling or comparison with field observations. For blowout spills, it is simply assumed that the Day 1 thicknesses would be used, i.e., 2.5 mm (0.1 in). The NAS report suggests that lesser slick thicknesses should be considered, and provides a good summary of observations from the few well-documented blowout spills in their review of the Genwest report, as follows.

Field Observations of Blowouts (Excerpted from NAS report on Genwest EDRC)

- Allen and Dale (1997) reported that early on the first day after oil was released from the *Exxon Valdez* onto a very calm sea, the thickness of the spreading Alaskan crude oil averaged 2.5 mm (0.1 inch).
- McAuliffe (1987) asserted that floating oil thicknesses resulting from blowouts would be less than that from surface releases because the oil from a blowout surfaces over a broader area than an initial area covered by a spill onto the water surface. He reported that during the release period (April 1977) of the Bravo Platform blowout in the Ekofisk oil field in the North Sea, a continuous slick 100 to 200 m (300 to 600 feet) wide and 1 km (3000 ft) long was estimated to be 1 mm (0.04 inch) thick.
- During the initial flow of the Ixtoc blowout in the Gulf of Mexico, oil thickness was estimated to be 0.07 mm (0.003 inch) on average. The spilled oil from the Bravo blowout spread on cold water, whereas the oil from the Ixtoc spread on very warm water.
- According to a report by Audunson et al. (1984), as summarized by McAuliffe (1987), the Statfjord crude oil subsurface experimental release in the North Sea, which simulated a blowout but where an oil and gas buoyant plume did not reach the surface, resulted in the thick part of the slick averaging 0.06 mm (0.002 inch) after 8 hours and decreased to a steady-state thickness (lasting at least 5 days) of 0.013 mm (0.0005 inch).
- Thus, for blowouts and surface spills, oil thickness has been observed to be initially (during the release and the first day) about 0.1 mm (0.004 inch) thick over warm water, about 1.0 mm (0.04 inch) thick over cool water, and about 2.5 mm (0.1 inch) thick on cold water.

Note: It is suggested here that the colder water of the North Sea may have reduced the oil spreading and led to a thicker slick. Of more significance is the fact that the Bravo blowout was a surface blowout. Subsea blowouts, as in the case of Ixtoc and Macondo, would likely be much thinner. Subsea releases, particularly those in deep water, have time to spread during their rise to the surface, resulting in much thinner slicks. Looking only at the subsea releases summarized above, initial slick thicknesses are in the range of a maximum of 0.1 mm (0.004 in) thick.

This is supported further in observations from the Macondo blowout, also summarized in the NAS report:

Observations of Macondo Supporting Lesser Thicknesses (excerpted from NAS report on Genwest EDRC)

For example, the Deepwater Horizon blowout in the spring and summer of 2010 in the Gulf of Mexico provided field evidence of the patchiness characteristics of an oil spill, with large areas of thick oil and emulsions being observed. Svejkovsky et al. (2012) reported that they used multispectral aerial imagery (Svejkovsky and Muskat, 2009) taken during overflights to classify and map observed floating oil into three thickness categories and to identify and map emulsions. They classified thick oil as greater than 0.09 mm (0.0035 inch), discontinuous or thinner oil as 0.016 to 0.08 mm (0.0006 to 0.0031 inch), and sheen as 0.008 to 0.015 mm (0.0003 to 0.0006 inch). One example map product for oil imaged near the source on May 6, 2010 (Svejkovsky et al., 2012, Plate 1b) was gridded by the committee using a cell size equivalent to a mid-range estimate of 1.6 km^2 (0.6 mi^2) swept by a skimmer in 12 hours. The maximum area of thick oil (greater than 0.09 mm [0.0035 inch]) in any single grid cell was 41% of the cell; with neighboring cells containing somewhat less oil coverage (30 to 39% in the closest four cells). The 20 grid cells with the highest areas of thick fresh oil (which were not contiguous) ranged in coverage from 5% to 41% of the 1.6-km^2 (0.6-mi^2) area. These observations were of oil near the spill site and within hours of release. For apparent emulsions, the results were similar: 30 to 44% of the six grid cells with the highest emulsion areas were covered by this oil type. Although the six grid cells with the highest coverage were not contiguous, 56 grid cells contained at least 5% coverage of emulsions. Emulsions were observed close to the source, so, although weathered, they could have been hours old or possibly up to a few days old if the oil was not transported far from the well. Based on the analysis of the Svejkovsky et al. (2012) image of May 6, 2010, thick oil patches (*note: defined here as greater than 0.09 mm)* might cover about 5 to 20% of the water surface in areas of concentrated oil away from the release point (i.e., in areas of “Day 2” or “Day 3” oil).

Blowout Modeling

Finally, in a study of deepwater blowout behavior for BSEE (then the Minerals Management Service) (SL Ross 1997), a range of blowout flow rates and water depths were modeled. The results showed initial slick thicknesses, *on average*, in the range of 0.05 to 0.10 mm (0.002 to 0.004 in) near the source of the blowout. “On average” is emphasized as it is recognized that there would be discontinuities, areas with oil that is thicker than average and areas with less. However, for the purposes of encounter rate planning, when a system would be covering a broad area over a period of time, it is important to look at an overall average slick thickness that would be encountered over time.

Summary

For blowouts, using an encounter thickness of 2.5 mm is not supported by field observations or theoretical modeling, and is problematic in practice. For example, a single system encountering oil at this thickness, with 500 feet of boom (and thus a 150-foot sweep width based on a 0.3 gap ratio) and towing at 1 knot, could encounter some 16,000 barrels of oil in a 12-hour period. As a result, three such systems could encounter 48,000 barrels per 12-hour day, in the range of the total daily volume of the Macondo blowout. Although such equipment was available, there is no evidence that these rates were achieved.

There have been few subsea blowouts, and the documentation on slick thicknesses is sparse. However, based on the information that is available, as well as by theoretical modeling, an initial near-source slick thickness of 0.1 mm (0.004 in) is recommended.