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IN-SITU BURNING OF SPILLED OIL

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Introduction

In-situ burning has been recognized for many years as an effective way to eliminate large quantities of spilled oil. Before the early 1980s, however, most attempts to burn spilled oil had to be carried out without the aid of fire-resistant booms. As a result, the effectiveness of such burns depended on the availability of other structures or forces (e.g., vessels, docks, shorelines, winds, ice) to keep the spilled oil thick enough to support combustion.

Laboratory and field investigations have now demonstrated that the effective, sustained combustion of oil on water requires that the oil being burned be at least 2 to 3 mm thick (about 1/10 in). Without a fire containment boom to maintain an adequate burn thickness, the combustion of uncontained oil will quickly cease when the oil reaches an average thickness of approximately 1 mm. Most accidental and deliberate burns of spilled oil at sea suffer from the effects of winds and waves that spread any uncontained oil quickly to a thickness that will not sustain combustion. Under such conditions, burning is usually limited to the region immediately adjacent to the spill source, the lee of the vessel/facility involved, and/or the structure, shoreline or ice against which the burning oil is herded by the wind or currents.

Now with the development of fire resistant booms (e.g., 3M Fire Boom), there are numerous situations where controlled *in-situ* burning of spilled oil can be carried out quickly, safely, and efficiently. Some of the more significant before burn experiences, the basics of controlled burning, and several different spill scenarios where burning could be used as an effective spill response technique are addressed here. The scenarios include offshore exploration and production operations, marine pipeline accidents, tanker accidents, and spills into river and stream environments.

Significant advancements have been made during recent years in

This issue is dedicated to *in-situ* burning of oil spills. Al Allen of Spiltec in Seattle reviews *in-situ* burning with particular emphasis on how it can be applied in spill situations. Al has developed a set of nomograms which can be used to calculate the boom capacities and burn rates. This will be of specific interest to those who wish to apply *in-situ* burning in the field.

the development of techniques and equipment for the safe and effective ignition and controlled burning of spilled oil. And, while many countries are now recognizing and including burning in their spill response plans, it is important to emphasize that combustion is not seen as a substitute for containment and physical removal of spilled oil. Conventional booming and skimming operations should always be conducted wherever such activities can be implemented safely and with a reasonable degree of effectiveness.

The potential for *in-situ* burning (as for the use of chemical dispersants) should be considered on a case-by-case basis to establish whether it should be used in conjunction with, or as a temporary alternate for, other more conventional cleanup techniques. A careful comparison of response techniques (Allen, 1988) reveals that there are often situations where burning (and/or chemical dispersants) may provide the only means of eliminating large quantities of oil quickly and safely. In some situations, mechanical recovery, burning, and chemical dispersants can be used simultaneously in reacting to various portions of a spill. The objective should be to find the right mix of equipment, personnel, and techniques that will have the least overall environmental impact.

The effects associated with a burn or no-burn decision are complicated, and require careful consideration of such risk factors as accidental secondary fires and the transport of smoke toward populated areas. These factors must then be weighed carefully against the effects and costs of not burning (e.g., oil contact with shorelines, birds, and mammals, shoreline cleanup costs, contamination of seawater intakes). For this reason, it is essential that the potential users and regulators of *in-situ* burning learn about combustion techniques/equipment as well as the environmental considerations that go into a meaningful evaluation of a decision to burn spilled oil.

For *in-situ* burning to be used safely and effectively, it is important that a burn decision be reached quickly (within minutes to a few hours at most). Unless the spill involves an ongoing release of oil over weeks to months (such as in a blowout), the "window-of-opportunity" for burning oil at sea is likely to be measured in hours or one to two days. The type of oil spilled, the wind and sea conditions at the time of spillage, and the degree of emulsification of the spilled oil will determine the feasibility of igniting and sustaining combustion. Experience has shown that a timely decision (and response) is essential, and that such decision making can be facilitated through advanced planning and implementation of guidelines for *in-situ* burning. Such guidelines are used in parts of the United States, and the author would be happy to provide more information upon written request.

Prior Burn Experience

One of the earliest major spill incidents involving burning was the grounding of the TORREY CANYON off the coast of Cornwall, England in 1967. With the release of nearly 95 000 tonnes of crude oil over approximately 12 days, numerous attempts were made to burn the oil using a variety of bombs, rockets, and other combustion promoters. The rapid loss of volatile fractions, the wind and sea states, the violent methods of ignition, and the lack of containment during burning all led to a relatively unsuccessful burn. During the years that followed, several spill incidents involved the burning of spilled oil, including the tanker ARROW in Chedabucto Bay, Nova Scotia (1970), the OTHELLO/ KATELYSIA collision in Tralhavet Bay, Sweden (1970), the ARGO MERCHANT grounding off Nantucket Island, Massachusetts (1976), the AMOCO CADIZ grounding off France (1978), the BURMA AGATE off Galveston (1979), and the collision of the ATLANTIC EMPRESS with the AEGEAN CAPTAIN in the Caribbean Sea (1979). The success of any *in-situ* combustion during these and many other spills in the 1970s was limited to situations where burning could take place in isolated thick pools (i.e., concentrations adjacent to the source, or in pockets trapped by ice, shorelines).

During the 1980s the same kinds of results were experienced during accidental fires at sea; however, toward the middle of that decade it had become clear that successful burning could be ensured with proper ignition procedures and controlled containment during the combustion process. Numerous experiments in the United States and Canada focussed on new techniques for the aerial ignition of oil slicks (Energetex Engineering, 1978; Dickins, 1979; Twardawa and Couture, 1980; Allen, 1986; 1987), and for the containment of burning oil using fire-resistant booms (Buist and McAllister, 1981; Spiltec, 1986; Allen and Fischer, 1988). These experiments included static tank tests exposing a fire containment boom continuously to burning crude oil for up to 24 hours. In 1988, an open water burn test was conducted by 3M and SINTEF (Trondheim, Norway) involving the deliberate ignition of 1900 L (500 gal) of Statfjord crude oil contained within 91 m (300 ft) of 3M Fire Boom. The Fire Boom was towed in a U-configuration while a Helitorch (from Simplex, Oregon, U.S.A.) was used to ignite the contained oil. The field trial was quite successful, resulting in the elimination of 95% of the oil in approximately 30 minutes.

On March 25, 1989, during the evening of the second day following the grounding of the EXXON VALDEZ, an estimated 57 000 to 114 000 L (15 000 to 30 000 gal) of North Slope crude oil were eliminated using *in-situ* combustion techniques (Allen, 1990). The oil was collected with 3M's Fire Boom towed in a U-configuration through slightly emulsified oil patches in the downwind region of the spill. Working with 150-m (500-ft) long tow lines, a (140-m-) (450-ft-) long boom was towed at about 1/2 to 3/4 knots (0.3 to 0.4 m/s) until the downstream portion of the "U" was filled. A small handheld igniter of gelled fuel was released from one of the tow boats so that is would drift back into contained oil. Shortly after ignition, the entire area of oil within the boom caught fire and burned for about 75 minutes. The intense portion of the burn lasted about 45 minutes, during which time the towing vessels could control the size of the fire by altering their speeds as desired. Upon completion of the burn, it was estimated that there was about 1150 L (300 gal) of stiff, taffy-like, easily recovered burn residue within the boom. Using three different approaches to calculate the volume of oil burned, it was estimated that between 57 000 and 114 000 L (15 000 and 30 000 gal) of oil were eliminated resulting in a burn efficiency of at least 98%.

Since these open-ocean burns were completed, numerous, additional, experimental burns have been conducted in the United States, Norway, and Canada. These experimental burns were completed in order to refine fire boom design and performance, to examine the feasibiity of burning highly weathered and emulsified oil, and to sample and evaluate the various products of combustion. The results of these and many other burns can be found in the proceedings of the International Oil Spill Conference (sponsored by the U.S. Coast Guard, American Petroleum Institute and Environmental Protection Agency) in the United States, and the Arctic and Marine Oil Spill Program Technical Seminar (sponsored by Environment Canada).

Basic Combustion Considerations

Oil Thickness: A vast majority of crude and refined oils will burn on water if the oil layer thickness is at least several millimetres and the ignition area and temperature are great enough to vaporize material for continued combustion. Experience has shown that at least 2 to 3 mm (1/10 in) of oil thickness is needed to prevent excessive heat loss from the oil layer to the water below. Nearly all *in-situ* burn tests with oil on water have revealed that combustion will cease quickly when the average film thickness is reduced to approximately 1 to 2 mm.

Oil Access: Towed-U-configurations with 150 to 300 m (500 to 1000 ft) fire boom (Figure 1) would be adequate to intercept oil slicks at swath widths of several hundred metres or more. Additional U-configurations, longer booms, and/or separate diversion systems (working with a a conventional boom in front of the fire boom) could be used to create exceptionally wide swath widths.

Boom Holding Capacity: As oil accumulates within a towed fire boom U-configuration the potential oil-holding capacity approaches several hundred barrels of oil per inch of oil depth within a relatively small portion of the contained area (Figure 1). An average oil layer thickness of only 15 cm (6 in) would represent

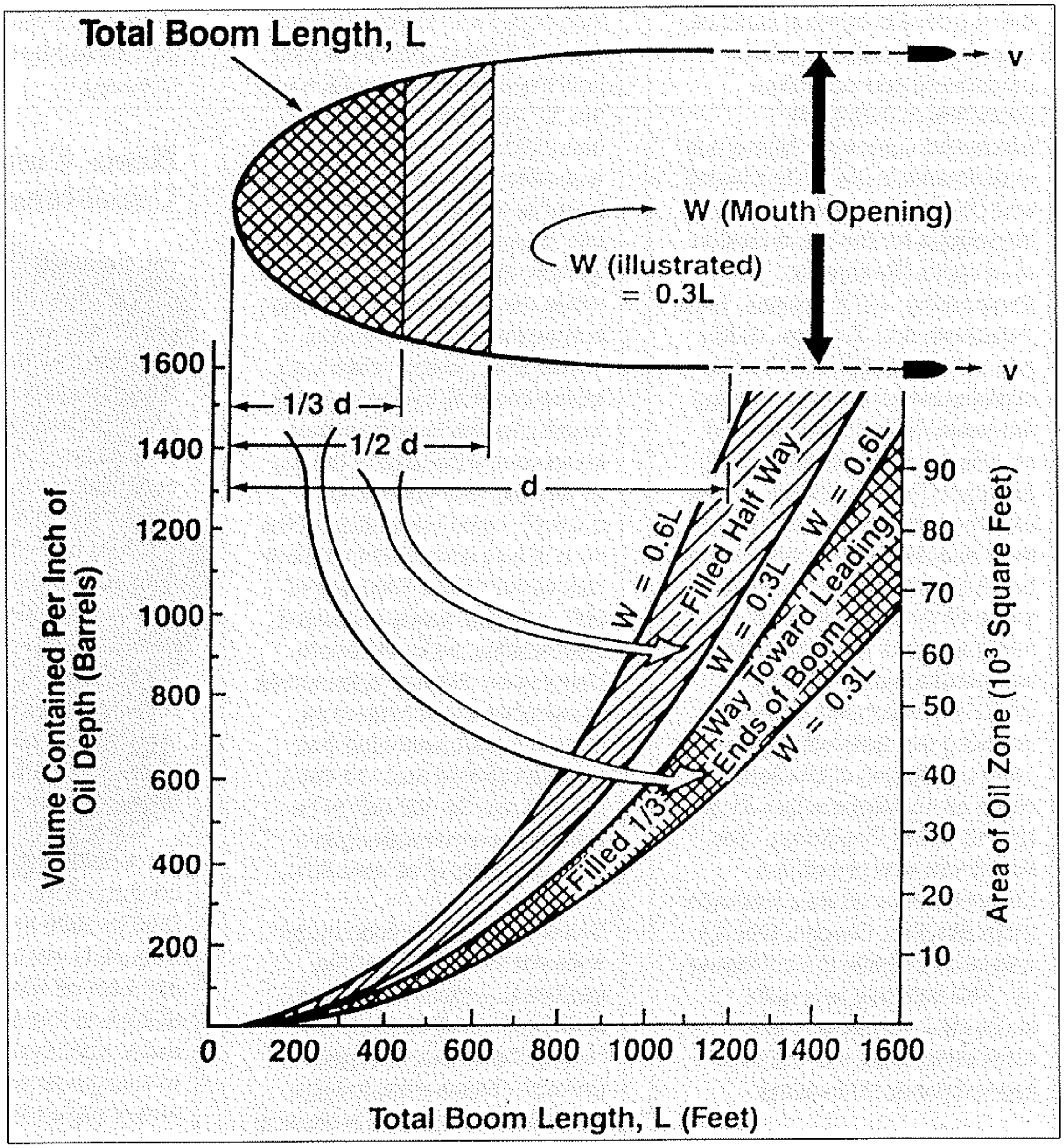


Figure 1
Boom Holding Capacity

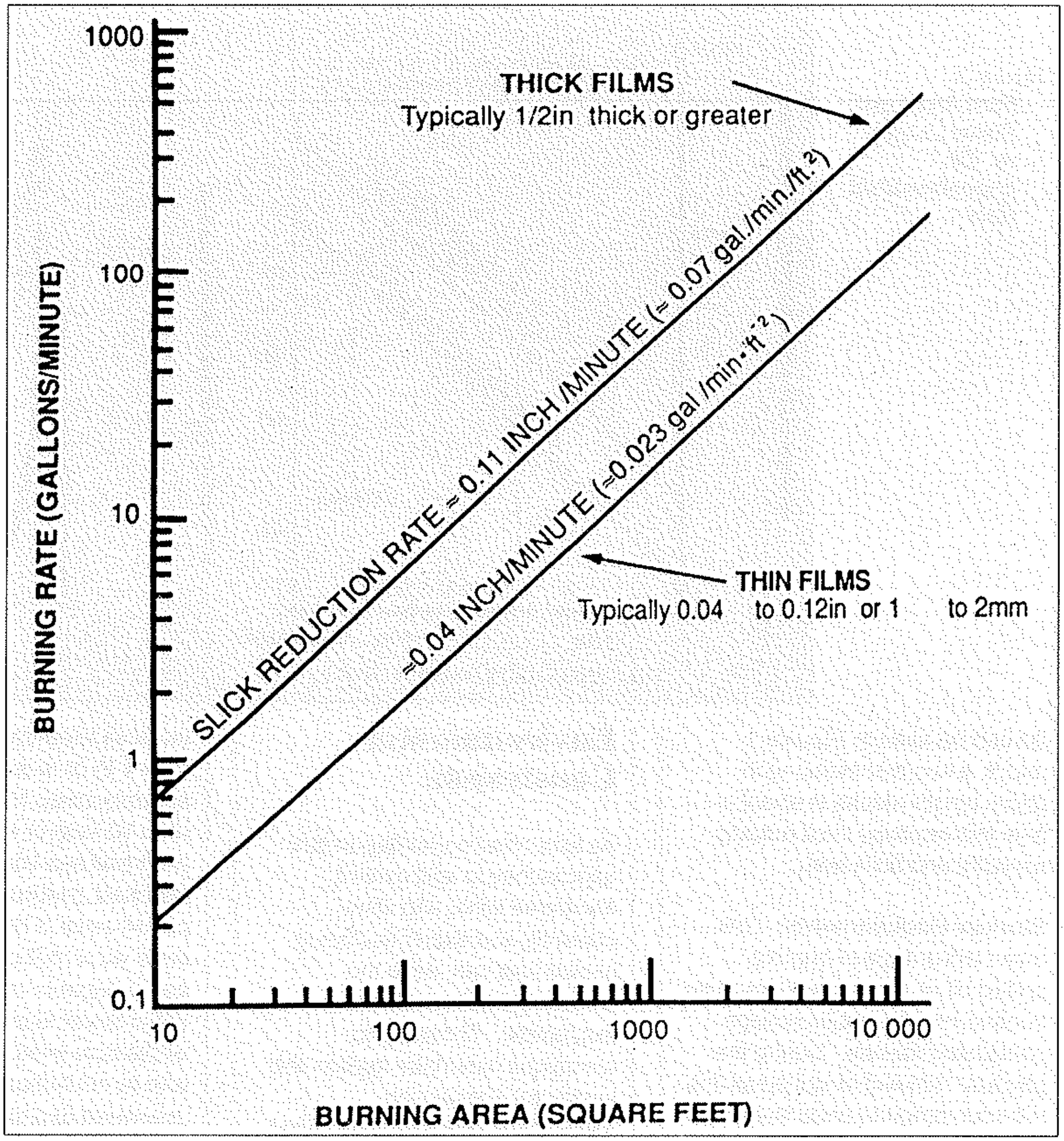
a holding capacity of over 600 barrels (more than 95 m^3) in the lower third of a 150-m (500-ft)long fire boom.

Burn Rate: Many controlled burn tests have revealed that floating pools of oil will normally burn with a thickness-reduction rate of about 2 to 3 mm/min (Figure 2). Experience has shown that this burn rate does not vary significantly with different oil types, degrees of weathering, and water content. The burn rate is lower, however, during the final (thin-film stage) of burning. The thickness-reduction rate for most oil spills can therefore be expressed as about 4100 L/d$\cdot$m^{-2} (0.07 gal/min$\cdot$ft^{-2} or about 100 gal/day$\cdot$ft^{-2}).

Efficiency: Burn efficiencies have consistently been well above 90% during numerous experimental and accidental burns of petroleum on water using a fire boom. The actual controlled burns referenced earlier (Spitsbergen and the EXXON VALDEZ) resulted in efficiencies of 95 to 98%. The 2 to 5% of the original oil volume left unburned is typically a viscous taffy-like material that floats and is easily recovered by hand.

Volume Control Rate: By combining information from Figures 1 and 2, the potential volume control rate associated with various boom lengths and, therefore, contained oil areas can

Figure 2
In-situ
Burn Rate

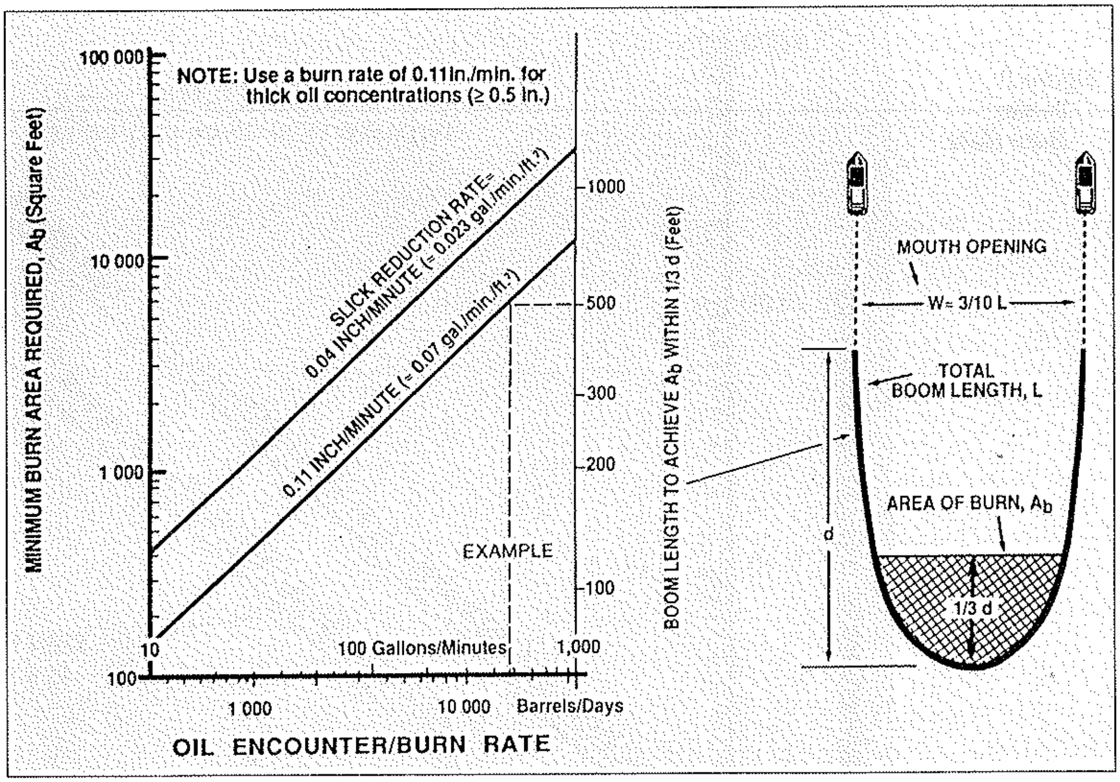


be illustrated (Figure 3). A single 150-m (500-ft) long fire boom can provide 560 to 650 m^2 (6000 to 7000 ft^2) for burning within the downstream third of the boom area. Using the burn rate of 4100 L/d• m^{-2}, a burn rate of about 1900 L/min could be achieved. If an average oil depth of 15 cm or about 600 to 700 barrels were contained within the boom, it would take about an hour to burn the contained oil. The full 1900 L/min would not be sustained during the final phase of the burn since the burn area would be continually reduced in size.

Depending on the nature of the spill, it may be necessary to collect oil within the fire boom and then move it to a safe location for burning away from the source of other heavy (potentially ignitable) oil slicks. By working two or three separate 150-m U-configurations (only one burning at a time), it could be possible to complete a burning nearly every hour. Over a 12-hour period, it is possible that approximately 8000 barrels (1300 m^3) of oil could be eliminated.

The overall elimination rate during a given burn could be increased substantially by slowing down the boom-towing vessels, thereby increasing the area of burning oil within the boom. Major increases in burn rate could also be realized by increasing the length of the fire boom in each U-configuration.

Figure 3
Burn Area and Boom Length vs. Oil Encounter/Burn Rate



As can be seen in Figures 1 and 3, a two-fold increase in boom length results in about a four-fold increase in oil holding capacity and burn area.

Storage Requirements: One major advantage of burning spilled oil *in situ* is that there is no need to provide major storage containers/vessels. During the physical removal of spilled oil it is not uncommon to need from two to five times as much storage volume as actual oil recovered. During a massive burning operation at sea, it may not be practical nor of environmental significance to attempt a recovery of any burn residue. However, should it be possible to recover the residue (without taking away critical support personnel/ equipment), this would involve a mere fraction (2 to 5%) of the oil burned.

Environmental Constraints

As with other boom-dependent approaches to spill control, excessive wind, sea state, currents, and debris (including broken ice) can make the containment of oil difficult to impossible. These same conditions can make ignition and sustained combustion (particularly with aged/emulsified oil) extremely difficult. Poor visibility, including night operations, can be a significant problem; however, once the oil is ignited, station keeping can be relatively easy when burning at or very close to the source. Ice, though a serious problem with booms, can be used to enhance burning without boom use if there is enough ice to limit the spread of oil and dampen wave action.

The "window of opportunity" for effective burning *in situ* generally involves wind-waves of about 1 m (3 to 4 ft) or less, and winds of approximately 15 to 20 knots (8 to 10 m/s) or less. Greater wind and sea conditions can be tolerated, particularly a long-period swell, if the fire boom has good wave-riding characteristics and is capable of reducing oil entrainment and splashover to an acceptable level. Towing a boom with its contained oil in a downwind direction, together with the wave-dampening effects of thick oil, will normally extend the burning "window" significantly. Much stronger winds can also be tolerated if the oil is relatively fresh (i.e., relatively volatile and of low water content). Once the oil is ignited and combustion has spread over a large area, stronger winds are of less concern.

The temporal "window of opportunity" may actually be quite broad, ranging from a few hours to several days. If the wind and seas distribute the spilled oil over a large area quickly, the resulting thinness, evaporative losses, and excessive areas may preclude the use of burning within a very short time. Even if it is possible to divert and concentrate a portion of the spill, the oil may be too emulsified to ignite. Controlled testing using various emulsions has shown that some oils can be ignited containing as much as 50 to 70% water. Other tests have shown that some oils are extremely difficult to ignite with only 10 to 20% water content. It is reasonable to assume that if the water content of an emulsified oil has reached the 30 to 50% level, the chances are very great that successful ignition will require large initial ignition areas (achievable using a Helitorch), the use of special wicking agents or promoters of ignition, and/or the use of chemicals to de-emulsify the oil before ignition.

The greatest environmental concern over *in-situ* burning as a spill response tool involves the atmospheric emissions from the combustion of petroleum. Numerous studies have been completed and many are underway (Benner *et al.*, 1990; Day *et al.*, 1979; Evans *et al.*, 1989; Fingas and Laroche, 1991; Mitchel, 1990) involving measurements and assessment of the products of combustion during the burning of oil spills. A team of oil spill and burning specialists has also been established involving U.S. and Canadian personnel from several government, academic, and oil industry groups. All pertinent data regarding the effects of burning oil *in situ* on the atmosphere are being gathered as well as data from studies involving the recent Kuwait fires and other investigations of smoke plumes from controlled burns in the United States and Canada.

These efforts so far reveal that airborne emissions from controlled oil spill burning operations are very likely of no serious concern — particularly at distances from population centres and other facilities/resources where such burning would be considered. *In-situ* burning, as with the application of chemical dispersants, is not considered a true "cleanup" technique; however, it is a viable response mode that can eliminate huge quantities of spilled oil quickly and efficiently. And, because burning can be accomplished simply and safely with very little logistical support, it is important that spill response planners and implementers at all levels become familiar with the potential merits and effects of burning.

If *in-situ* burning is to be used successfully, it must be considered and prepared for before a spill event. Those responsible for purchasing necessary equipment, training personnel, preparing response plans, and applying for or approving of burn permits must move to be prepared well in advance of a spill. As appropriate, guidelines need to be established for the assessment of trade-offs involving environmental effects, safety, etc. for burning as well as other response options. It is important that the "window of opportunity" for *in-situ* burning not be lost due to ignorance, unpreparedness, and/or time-consuming governmental reviews.

Representative Scenarios

The oil spill scenarios presented in Figures 4 to 10 are provided as examples of situations where *in-situ* burning could be considered as a viable response technique for the control of spilled

Figure 4
Relocation and Burning of Oil Collected at Spill Source

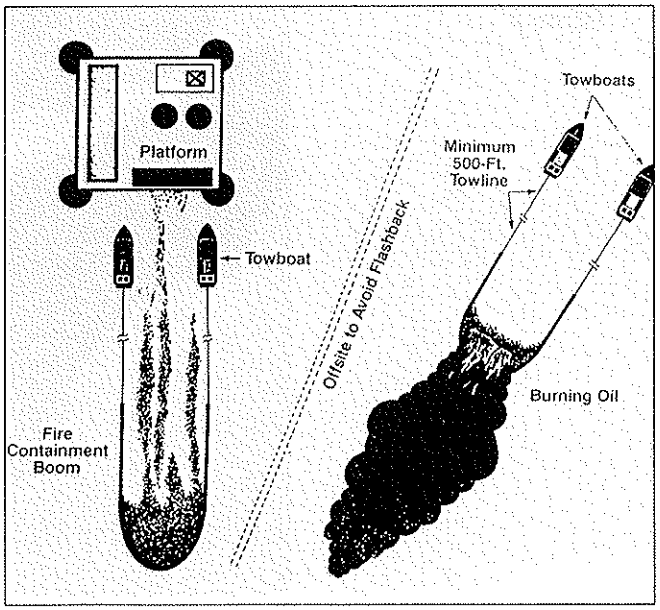


Figure 5
Containment and Burning of Oil Downstream of Burning Spill Source

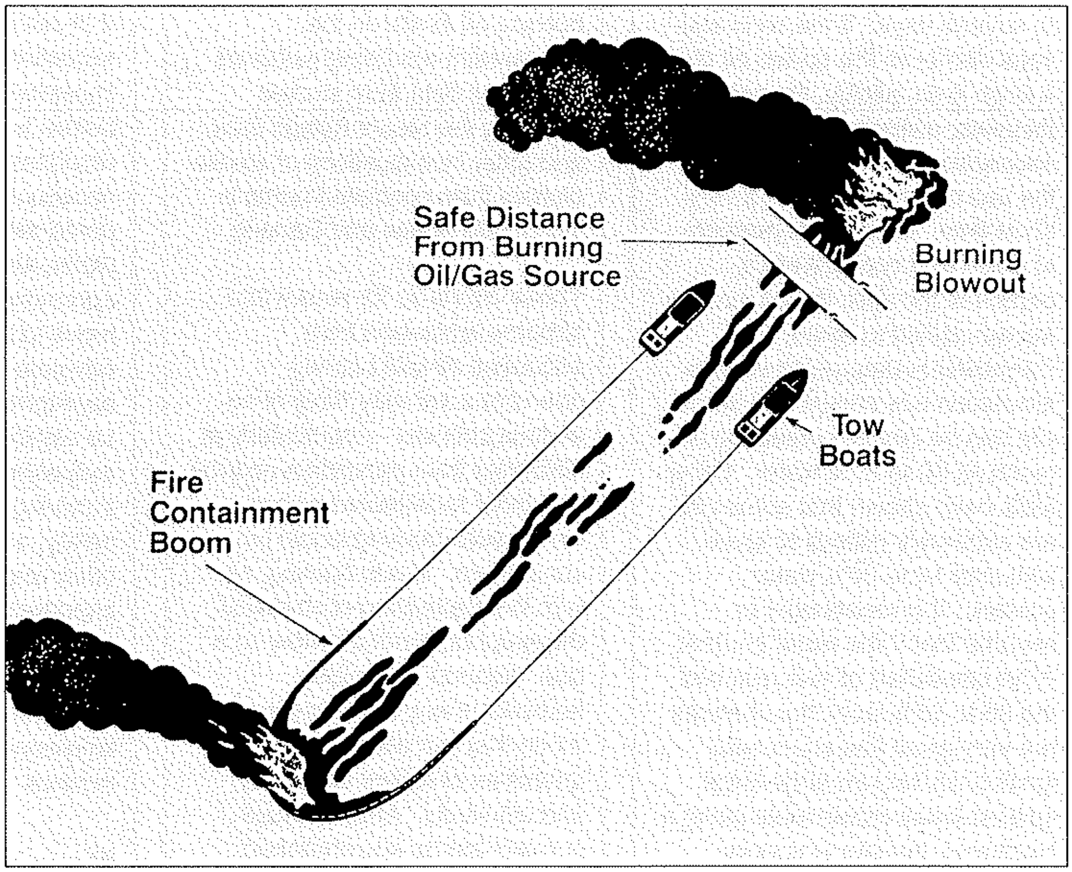


Figure 6
Immediate Containment and Burning of Oil at Subsea Blowout

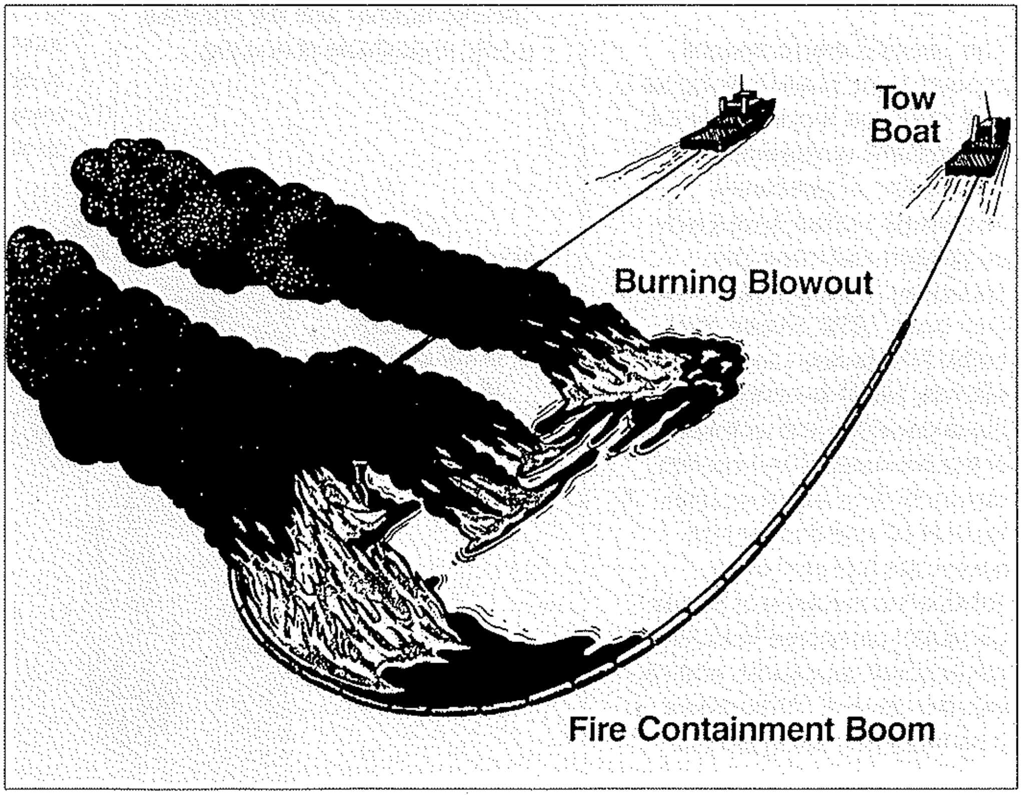


Figure 7
Burning of
Oil Over
Subsea Pipeline
Leak

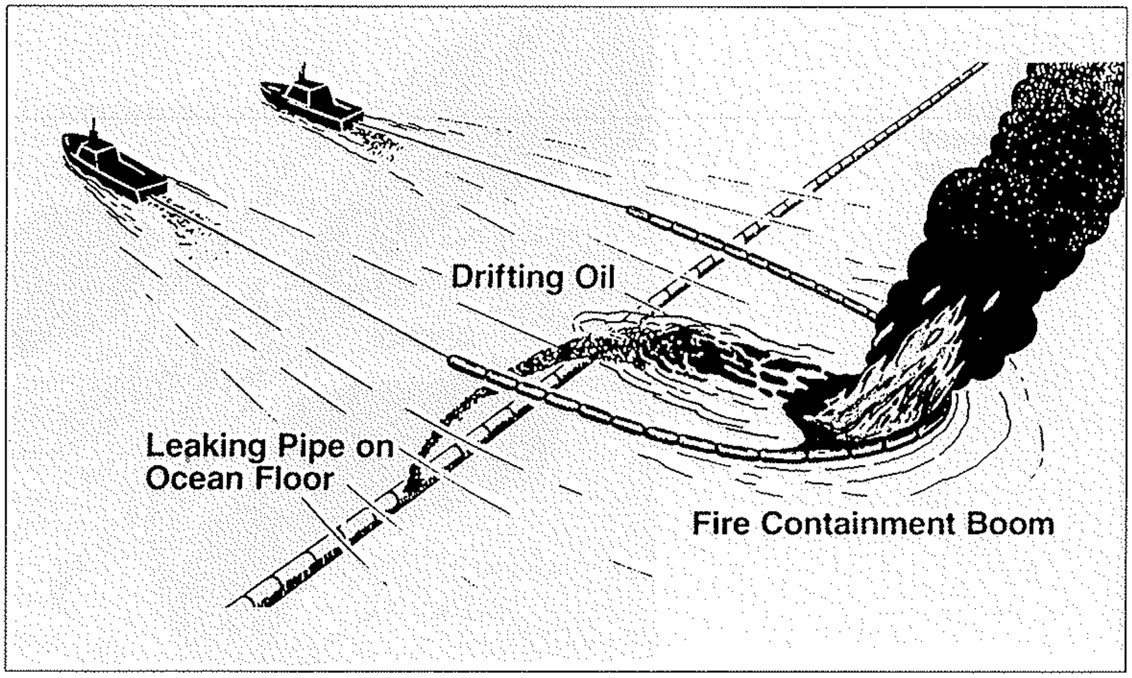


Figure 8
Burning of
Oil During
Tanker
Accidents

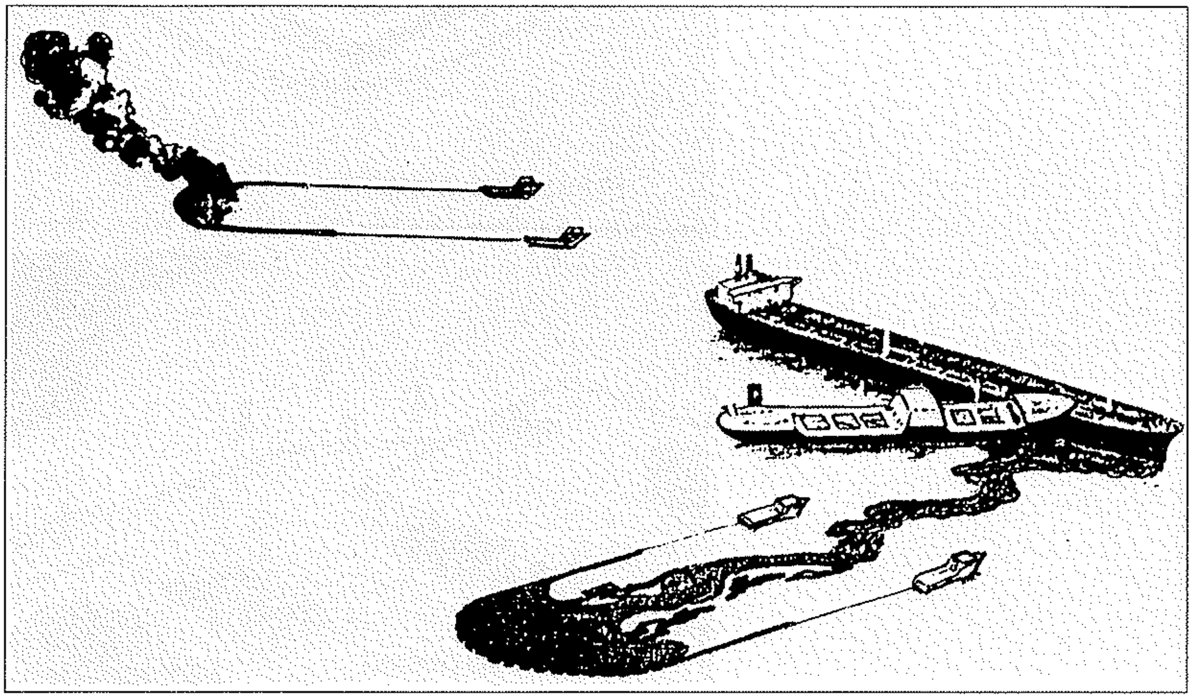


Figure 9
Burning of Oil Released to Rivers and Streams

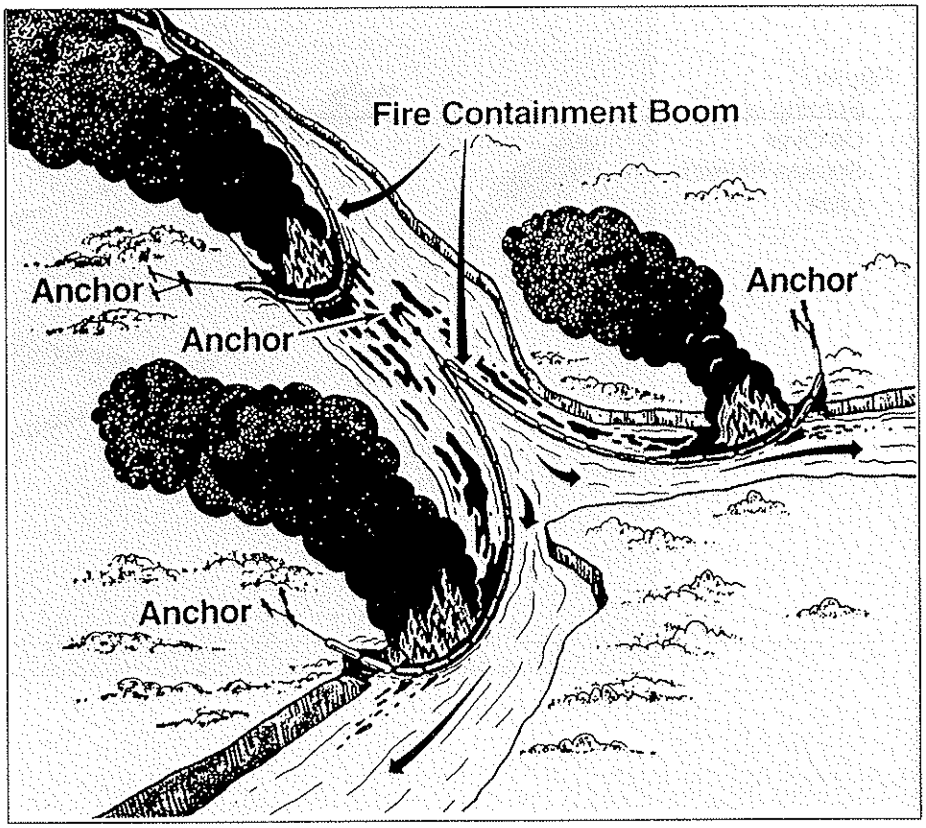
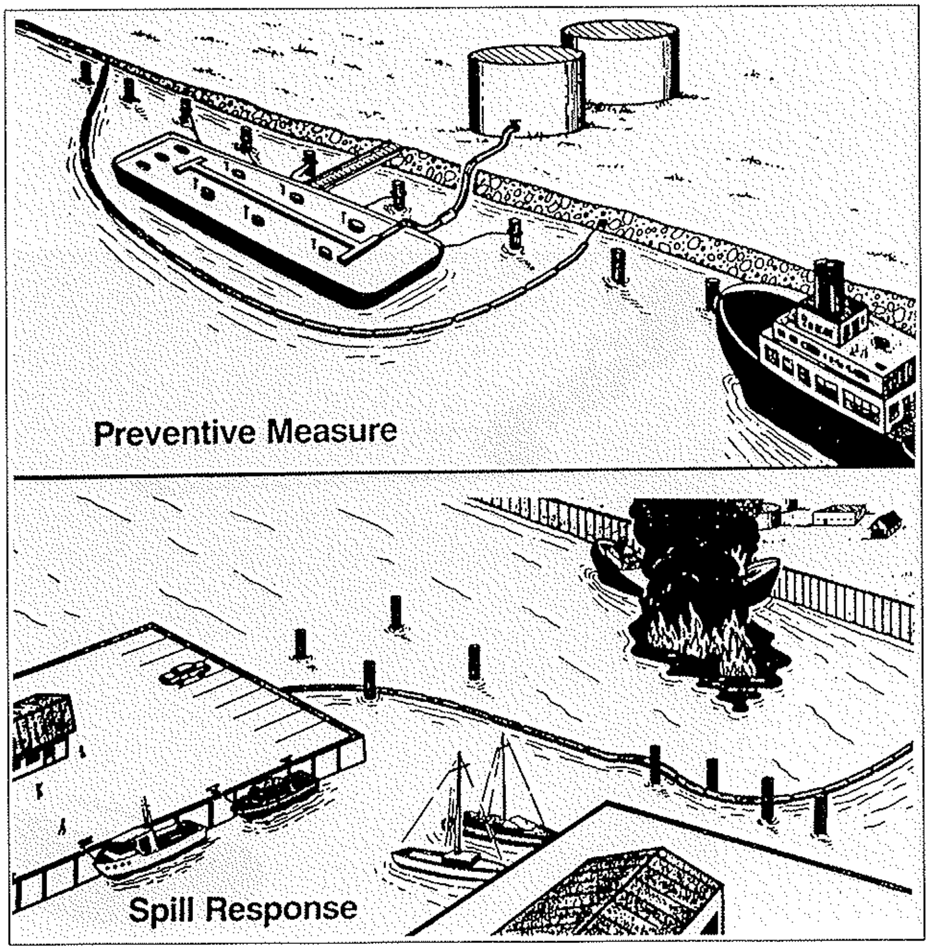


Figure 10
Isolation of Accidental Marine Fires



oil. It is recognized that the actual deployment of fire containment boom and ignition systems would be contingent upon government approvals (if appropriate), the nature and condition of the spill source (e.g., already burning, potentially explosive, involved in salvage/evacuation efforts, etc.), and the environmental conditions at the time of the spill.

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To broaden the scope of this newsletter, and to provide more information on industry and foreign activities in the field of spill control and prevention, readers are encouraged to submit articles on their work and views in this area.