IN-SITU BURNING:
A New Technique For Oil Spill Response

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1. INTRODUCTION

Large oil spills in coastal waters always draw increased public and regulatory attention to the difficulties of containing and recovering an oil spill on water. Massive releases of oil spread rapidly over large areas; they are transported over great distances by wind and currents; and they are altered substantially by many physical, chemical and biological processes. Changes in density and viscosity, together with the formation of stable water-in-oil emulsions, for example, often complicate the handling of the oil and increase the amount to be recovered and stored by as much as 2 to 3 times the original volume spilled. It is therefore extremely difficult to access a major portion of the spill in a timely manner, and to recover and store even that which can be accessed.

The author's experiences during such spills as the Santa Barbara, California spill (1969), the Mizushima, Japan spill (1974), and the Exxon Valdez spill (1989) provide lasting and humbling awareness of the speed with which large spills can escape man's control. As was observed in these three spills, millions of gallons (thousands of cubic meters) can easily spread over tens to hundreds of square miles (2.59 square kilometers per square mile) within two to three days of exposure on open water. <u>Area</u> increases necessitate many control systems with very high oil encounter rates. <u>Volume</u> increases, because of water uptake, necessitate the availability of enormous oil/water temporary storage containers.

Such problems involved with the mechanical removal of spilled oil demonstrate the need for immediate response to large oil spills with <u>all</u> available techniques, including the application of chemical dispersants and the use of controlled combustion in place (i.e., “in-situ burning”). As a relatively new response technique, controlled in-situ burning has already been used to eliminate large quantities of oil quickly and economically. In 1998, 3M and SINTEF (Trondheim, Norway) conducted an open-water burn test off Spitsbergen involving 500 gallons (1.9 cubic meters) of crude oil contained in 300 feet (91 meters) of 3M Fire Boom (now American Fireboom, made by American Marine, Inc. in Cocoa, Florida, USA). The Fire Boom was towed in a U-configuration while a Heli-torch (from Simplex in Portland, Oregon, USA) was used to ignite the contained oil, 95% of which was eliminated in about 30 minutes.

On March 25, 1989, during the evening of the second day following the grounding of the *Exxon Valdez* in Prince William Sound, Alaska, an estimated 15,000 to 30,000 US gallons (57 to 114 cubic meters) of North Slope crude oil were burned (Allen, 1990). The oil was collected within 450 feet (136 meters) of 3M/American Fire Boom towed in a U-configuration through slightly emulsified oil patches in the downwind region of the spill. The contained oil was towed to a safe location away from the main slick, and a surface igniter was allowed to drift back into the oil. After several minutes, sustained combustion was achieved with a resulting intense burn of about 45 minutes and a removal efficiency of approximately 98%.

Numerous other experimental burns have been conducted in the United States, Norway, and Canada. One of the most significant experimental burns (involving more than 25 agencies from Canada and the United States) was conducted off Newfoundland, Canada in August, 1993. Working with more than 20 vessels, 7 aircraft and 230 people, approximately 200 sensors or samplers were employed during two separate burns with the 3M/American Fireboom to monitor numerous physical parameters and combustion products. Costing nearly $7 million (Canadian), the Newfoundland Offshore Burn Experiment (NOBE) resulted in the combustion of more than 20,000 US gallons (or 77 cubic meters) of crude oil.

The controlled "in-situ" burning of spilled oil, used properly with due consideration for safety and exposure to combustion by-products, can eliminate large quantities of oil more quickly and cheaply than traditional mechanical removal methods. Furthermore, burning removes one of the weakest links in mechanical removal, the need to store and dispose of large quantities of recovered oil and water. This Paper examines how and why response planners should consider the burning of spilled oil as one of a number of important tools available to them.

2. MODES OF RESPONSE

2.1 Mechanical and Non-Mechanical Response

Spill contingency planners have numerous equipment options in designing a response package for a given facility, vessel, or operation, but these options fall into the two broad categories of mechanical containment/recovery and non-mechanical removal (primarily in-situ burning and the application of chemical dispersants). What is important for planners ---and for regulators and the public as well--- to realize is that these two categories of response are not mutually exclusive. To provide the most effective response under the widest range of conditions, the Incident Commander should have options from both categories.

Containment & Recovery: In the mechanical category, there are many different types and sizes of oil containment booms, skimmers, pumps, and storage devices that are used to mechanically deflect, corral and remove floating oil from water. Containment booms are floating barriers typically towed by two vessels to contain and thicken oil so that it can then be removed more effectively with skimming devices. Some booms are relatively small with shallow drafts of less than 1 to 2 feet (less than 1/2 meter) for use in calm harbor situations or in rivers with low to moderate currents. Larger booms with drafts of 3 to 6 feet (or about 1 to 2 meters) are often selected for use offshore in rougher waters. Regardless of the size, however, most booms will begin to lose oil through entrainment or splash-over as short-period, wind-waves approach wave heights of 3 to 5 feet (about 1 1/2 meters). The skimmers available today range from small portable devices to large dedicated, self-propelled, skimming vessels. Whether operated from within the hull of a vessel or as an over-the-side skimming system, most skimmers suffer significant reductions in efficiency as wind-driven breaking waves build to wave heights of 1 to 1 1/2 meters.

Dispersants: As a non-mechanical response technique, dispersant application involves the use of a variety of different chemicals designed to facilitate the breakup of an oil slick so that it is dispersed into small droplets suspended within the water column. In this form, the oil can be naturally broken down and decomposed much more rapidly. The other advantage is that dispersed oil tends not to stick to objects including animals and shoreline materials. Some of the early dispersants included relatively toxic hydrocarbon solvents, and were used in massive doses. Dispersants today have relatively low toxicities and are used at dispersant-to-oil ratios of typically 1:20 to 1:50 or less. The use of dispersants requires relatively fresh oil (preferably less than 12 hours and rarely more than 24 to 48 hours after spillage), and sufficient surface energy (a light wind-chop or more) to aid with the dispersion process. With adequate water depth, good chemical/oil interaction, and adequate mixing, dispersants can help to prevent a large oil slick from coming ashore in sensitive areas.

Burning: Response planners have known for some time that in-situ burning can be an effective way of eliminating large quantities of oil quickly at sea while minimizing the amount of recovered product that must be transferred, stored, and disposed of elsewhere. In-situ burning can involve the combustion of spilled oil that is uncontained on the water's surface or contained either naturally (e.g., by a shoreline or the side of a tanker) or by means of a fire-resistant containment boom. Such fire-resistant containment boom, of course, is subject to the same environmental constraints (wind, waves and currents) that influence the use of conventional booms. Numerous laboratory tests and several at-sea trials have shown that relatively fresh oil on water (preferably less than a day or two old) can be ignited if the oil is at least 0.1 inch (that is 2 to 3 millimeters) thick. The more weathered or emulsified the oil, the greater the thickness required for ignition and sustained combustion. Experience has shown that the Heli-torch (a helicopter-slung system involving the release of burning gelled fuel) is an excellent aerial ignition system for the burning of spilled oil. With nearly 20 years of proven, safe use in several countries, the Heli-torch offers an effective means of igniting even weathered and emulsified oils (Allen, 1992). Once ignited, most tests have shown that a contained relatively thick oil slick can be burned with removal efficiencies of from 95% to 98% or more (Allen 1991a,b).

The development of fire-resistant containment booms in the 1980s provided response organizations with a means of effectively containing an oil slick to provide the thickness needed for burning. Fire-resistant boom technology started with the Dome Petroleum stainless steel boom in Canada in the l970’s and has led to the development of a number of lighter & less expensive fire containment booms. Among these products, only the American Fireboom (also known as 3M Fire Boom) has had extensive large-scale tests with burning crude oil at sea. The American/3M Fireboom makes use of stainless steel, 3M-patented ceramic fibers and a unique high-temperature flotation core to form a boom that looks and behaves like standard containment boom. This fire-resistant boom, however, has survived the rigors of burning oil for up to 48 hours in a static test tank, and it has been used during four full-scale, open-water burns at sea, including the Prince William Sound burn in 1989 (Allen, 1990, 1992 & 1994).

2.2 Advantages and Disadvantages

Containment & Recovery: As already noted, the performance of mechanical containment and recovery systems strongly depends on wind and sea conditions, whether or not ice or debris are present in the water, and how weathered the oil is. In sea states of 3 to 4 (Beaufort Scale), most booms and skimmers begin to lose effectiveness. Short-period wind-waves of 3 to 5 feet often lead to significant losses of oil from a boomed area. These losses may be substantial during the time that would normally be required to physically recover the contained oil.

An important limitation of mechanical removal is the fact that skimming systems by their nature do not recover pure oil from the water's surface. The amount of water recovered with the oil may easily range from 2 to 3 times the volume of oil recovered. Some of this water may be entrained within the oil (as a water-in-oil emulsion), while some may be recovered as "free" water which could be decanted and possibly discharged. The result is the need for a large amount of storage capacity on scene. In fact, the availability of adequate on-scene storage capacity is often cited as the primary limiting factor for a mechanical recovery operation.

While mechanical response techniques have their limitations, they have at least one distinct advantage: they are the only mode of response with a broad time window. Mechanical response can go on indefinitely, even after spilled oil has weathered and come ashore on distant beaches. Of course, one must consider the environmental exposures that may occur over such a broad time window, as well as the financial costs of such a prolonged cleanup operation. Few organizations have the resources to continue a spill response operation indefinitely.

Non-mechanical techniques offer an important alternative to mechanical response; and while they may be limited to a relatively narrow "window of opportunity," they have the important advantage of being able to eliminate large volumes of oil quickly where mechanical removal is very time consuming and very expensive.

Dispersants: Effective dispersant application results in the dispersion of an oil slick as very small droplets in the upper part of the water column. The potential impacts of those elevated concentrations of oil (typically at significant concentrations for only minutes to a few hours in open water) must be considered by any regulators charged with authorizing dispersant application. With successful dispersion, the need for storage of recovered oil is eliminated, and the logistical support requirements for response to even a major spill are kept to a minimum. For spills covering very large areas, the successful application of dispersants will require the preplanning and staging of dispersant and application equipment, one or more large fixed-wing aircraft, a spotter aircraft, facilities for reloading and refueling the aircraft, and trained personnel available on short notice to operate these equipment. Any dispersant application program will require good visibility, sufficient wave action for good mixing, relatively fresh oil, and a dispersant that is known to be effective for the oil and water salinity involved. In addition, it may be necessary to satisfy certain regulatory constraints regarding water depth and/or predesignated zones for acceptable use.

Burning: In-situ burning using fire-resistant containment boom is subject to some of the same environmental constraints as mechanical removal. Since fire boom behaves like standard containment boom, the same wind and sea limitations for the containment of oil apply. However, the key differences between the two methods are the speed with which burning can remove large quantities of oil and the fact that the need for recovery and storage is nearly eliminated.

Contained relatively fresh crude oil on water burns at a rate of approximately 0.07 US gallons per minute per square foot (2.85 liters per minute per square meter). At that rate, burning within a 500-foot (152-meter) length of fire boom towed by two vessels can easily eliminate as much as 500 US gallons (1.9 cubic meters) per minute, or more than 700 barrels of oil per hour (assuming an effective containment area of approximately 7,000 square feet or 650 square meters within the boom). The contained burn area selected for this example (double cross-hatched area of Figure 1) represents a very small region within the boom extending from the downstream apex of a U-configuration forward approximately 1/3rd of the distance to the leading ends of the boom. By reducing the towing speed, the oiled area within the boom (and therefore the burn area) could be allowed to increase by a factor of 2 to 3 or more. The rate at which oil would then be consumed could also increase by the same factor. Figure 1 also illustrates the approximate volume of oil (in barrels per inch of oil depth) that could be captured at normal towing speeds for various boom lengths and oil/boom configurations. Examination of Figure 1 reveals that a single 500-foot (152-meter) boom with oil averaging only 4 inches (about 10 centimeters) in depth within the area represented by "1/3d" in the figure, could hold about 400 barrels (or 64 cubic meters) of oil. Note that a doubling of the boom length to 1000 feet (a little over 300 meters) would increase the oil holding capacity (and therefore the burn potential for a single boom load) by a factor of four. Thus it is conceivable that a single 1000-foot-long U-configuration (all or only partly comprised of fire boom) could involve the collection and combustion of at least 250 cubic meters of oil.

With removal efficiencies typically falling between 95% and 98%, the above example could result in the elimination of approximately 240 cubic meters or more, and very likely involve a completion of the burn in less than 1 hour (each inch or 25 to 30 millimeters of oil would burn off in about 10 minutes). In addition, the amount of residue that would need to be recovered (if at all) would be very small compared to the large volumes of oil and water recovered during typical skimming operations. The logistical requirements to support in-situ burning are thus much simpler and the time needed to eliminate large quantities of oil is relatively short.

A comparison of the costs of mechanical removal, dispersant application, and in-situ burning reveals that burning is also the cheapest method. The following costs (based on US dollars, 1993).

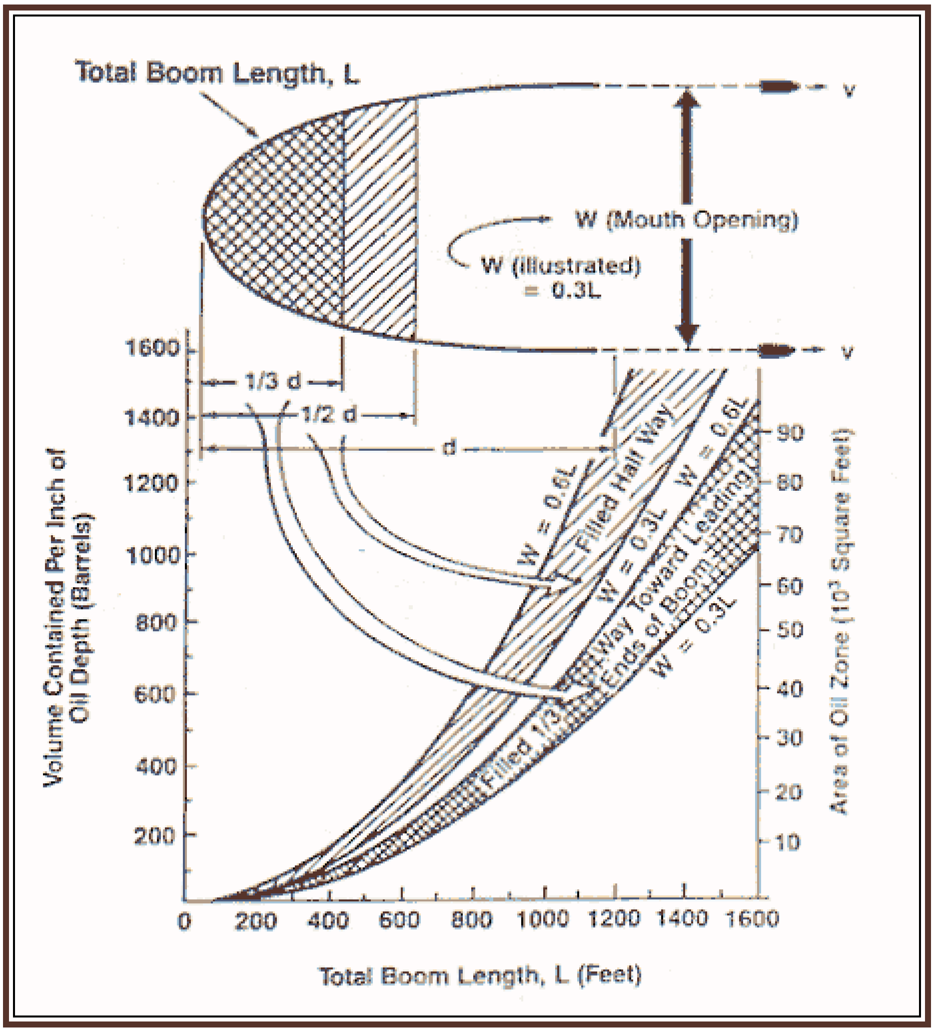

Figure 1 Oil area and volume estimates for various U-boom configurations at normal towing speeds of 1/2 to 2/3 knot (0.93 to 1.23 kilometers/hour.

were estimated using representative mechanical, dispersant, and burning systems for the recovery/elimination of approximately 8,000 to 10,000 barrels (1,272 to 1,590 cubic meters) of oil in a 12-hour period: mechanical, $100 to $150 per barrel of oil; dispersants, $50 to $100 per barrel; and in-situ burning, $20 to $50 per barrel (Allen and Ferek, 1993).

2.3 Environmental Constraints

It is clear that in-situ burning is an attractive and cost-effective means of dealing with spilled oil on water. However, the use of non-mechanical methods such as dispersants and in-situ burning is clearly inappropriate in some cases. For example, dispersants applied to an oil slick in shallow, sensitive, nearshore waters could be more damaging environmentally than allowing the oil to reach certain types of shorelines. Similarly, wind and atmospheric conditions would have to be considered carefully for the proper use of in-situ burning close to shore. If a spill were near a coastal city and the wind could blow smoke directly toward that population center, it may be inappropriate to consider burning.

Since various products of combustion enter the atmosphere from in-situ burning, some opponents of burning suggest that air pollution is simply being substituted for water pollution. It is most important to realize, however, that approximately one-third or more of the volume of most crude oils consists of volatile hydrocarbons, many of which are considered toxic and which will evaporate from an unburned oil slick anyway. These volatile hydrocarbons are eliminated by burning.

The primary products of in-situ combustion of crude oil are carbon dioxide and water vapor. About 90% to 95% of the carbon burned is released to the atmosphere as carbon dioxide, while particulates in the plume commonly account for approximately 10 percent of the original oil volume burned. During the Newfoundland Offshore Burn Experiment (NOBE) all compounds measured at ground level, including particulates, were found to be below health concern levels beyond 500 feet (approximately I50 meters) from the fire. Minor amounts of gaseous pollutants are emitted (carbon monoxide, sulfur dioxide, nitrogen oxides, etc.), however these too are reduced to insignificant levels rapidly and within a short distance downwind.

Some polynuclear aromatic hydrocarbons (PAHs) are emitted; however, the mass released is considerably less than the amount in the original oil since PAHs are consumed during the combustion process.

A great advantage of burning is the fact that the products of combustion are diluted in the air above and downwind of the burn, dispersing rapidly to background levels. The relatively localized short-term impact on the atmosphere should be compared with the potential long-term impact of oiling great stretches of shoreline if the oil is not removed from the water's surface. Furthermore, the volatile toxic hydrocarbons that would have evaporated from the surface of the slick are burned instead (Allen and Ferek, in press).

2.4 Role In Contingency P1anning

Offshore spill response organizations should be prepared to respond with both mechanical and non-mechanical equipment. Many oil spill response organizations in the United States, including Alaska and Hawaii, already have dispersant application capabilities. Many of these same groups are also leading the way in acquiring in-situ burn equipment and in training personnel for the controlled combustion of spilled oil on water. With some of the largest state-of-the-art response equipment inventories in the world, these organizations are preparing for response to a major spill event in nearly any of the offshore waters of the United States using the latest technology for both mechanical and non-mechanical response. During the past few years, several other response organizations outside the United States (e.g., Europe & Asia), have also expanded their capabilities to include in-situ burning.

Spill response planners are becoming increasingly aware that major offshore spills can rarely be handled effectively with mechanical response techniques alone. Equally important is the realization that chemical dispersant application, while having a high oil encounter rate, may have some significant constraints involving availability of equipment, water depth, mixing energy, and a relatively short window of opportunity for successful use. To those who have examined the full potential of in-situ burning, it is clear that deliberate, controlled burning also has some significant shortcomings that will preclude its use for certain spill scenarios. If wind and sea conditions are too severe for the use of conventional containment booms, it is likely that fire-resistant booms will also have difficulty in containing oil for a burn. If spilled oil has weathered and emulsified to the point that certain mechanical systems can not be used effectively or that dispersants would be ineffective, there is the likelihood that ignition of the oil could be difficult to impossible.

In order to deal with major offshore/coastal spills, response planners need as many tools as they can get. Mechanical removal, dispersant application, and in-situ burning are important response techniques that have unique advantages and disadvantages. If these factors are understood and considered carefully by knowledgeable planners, then mechanical and non-mechanical tools can be used to enhance and broaden response capabilities under a range of environmental conditions.

3. POTENTIAL BURN SCENARIOS

There are numerous situations where in-situ burning could be considered a viable response technique for the elimination of spilled oil from offshore exploration and production operations, marine pipelines and tankers, and from spills into rivers and streams. These burn scenarios can be covered under three broad categories: containment and controlled burning of spilled oil, burning of uncontained and/or naturally contained oil, and control and suppression of accidental marine fires.

Fire boom and aerial ignition systems can be used to collect, contain and ignite oil for controlled burning in a number of ways. Typical scenarios include:

- Collection of oil with relocation for a controlled burn at a safe distance from an unignited spill source - Figure 2.
- Containment and burning of oil downstream of a burning spill source (drifting, if necessary, with strong currents - Figure 3.
- Immediate containment of burning oil at its source - Figure 4.
- Collection, relocation, and burning of oil that has already spread over large areas - Figure 5.
- Controlled burning of oil trapped at shoreline - Figure 6.

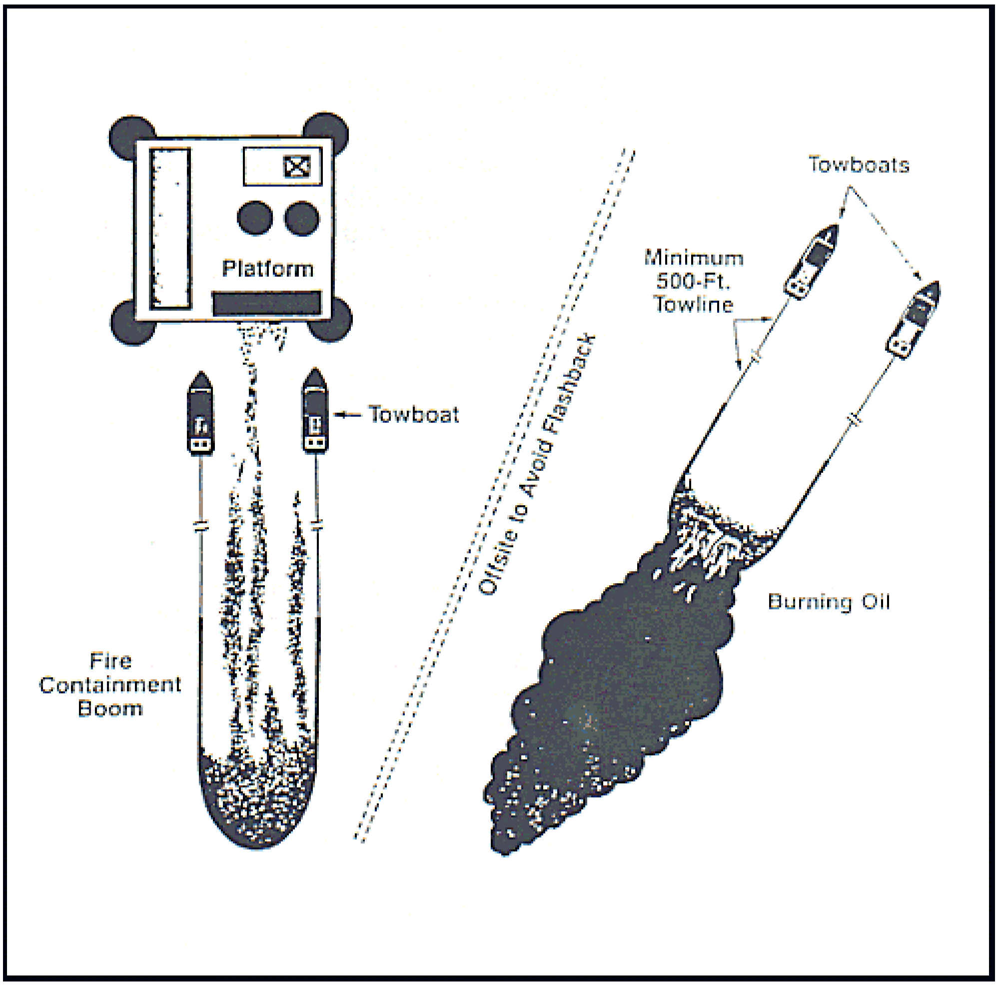

Figure 1 Containment, relocation and burning of oil away from unignited spill source.

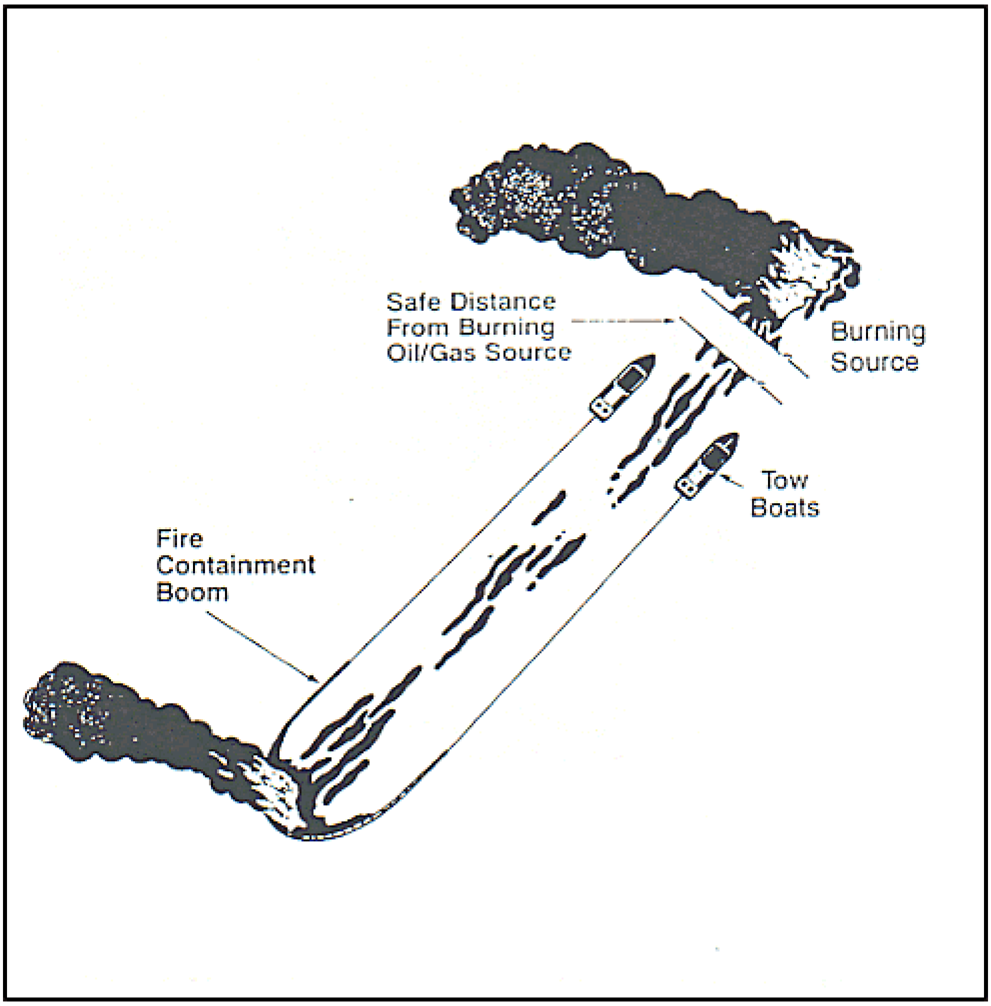

Figure 2 Containment and burning downstream of ignited spill source.

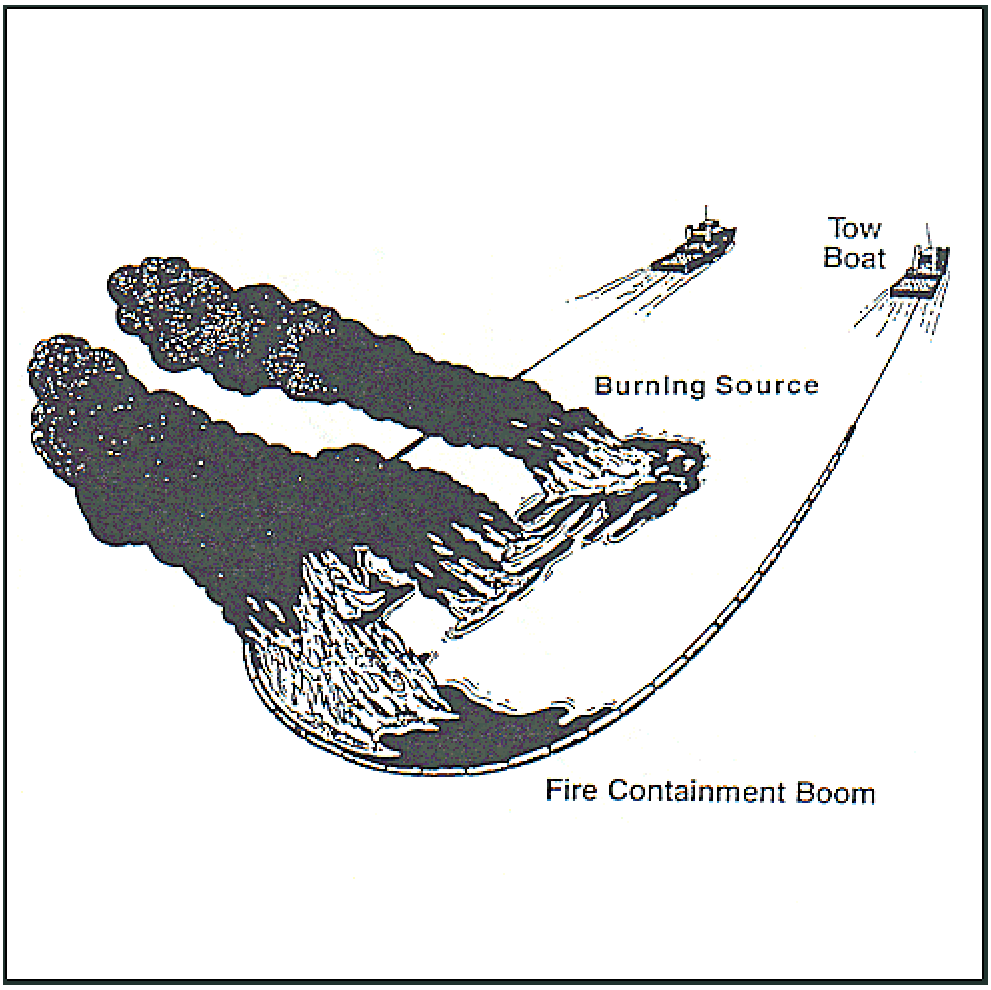

Figure 3 Immediate containment of burning oil at its source.

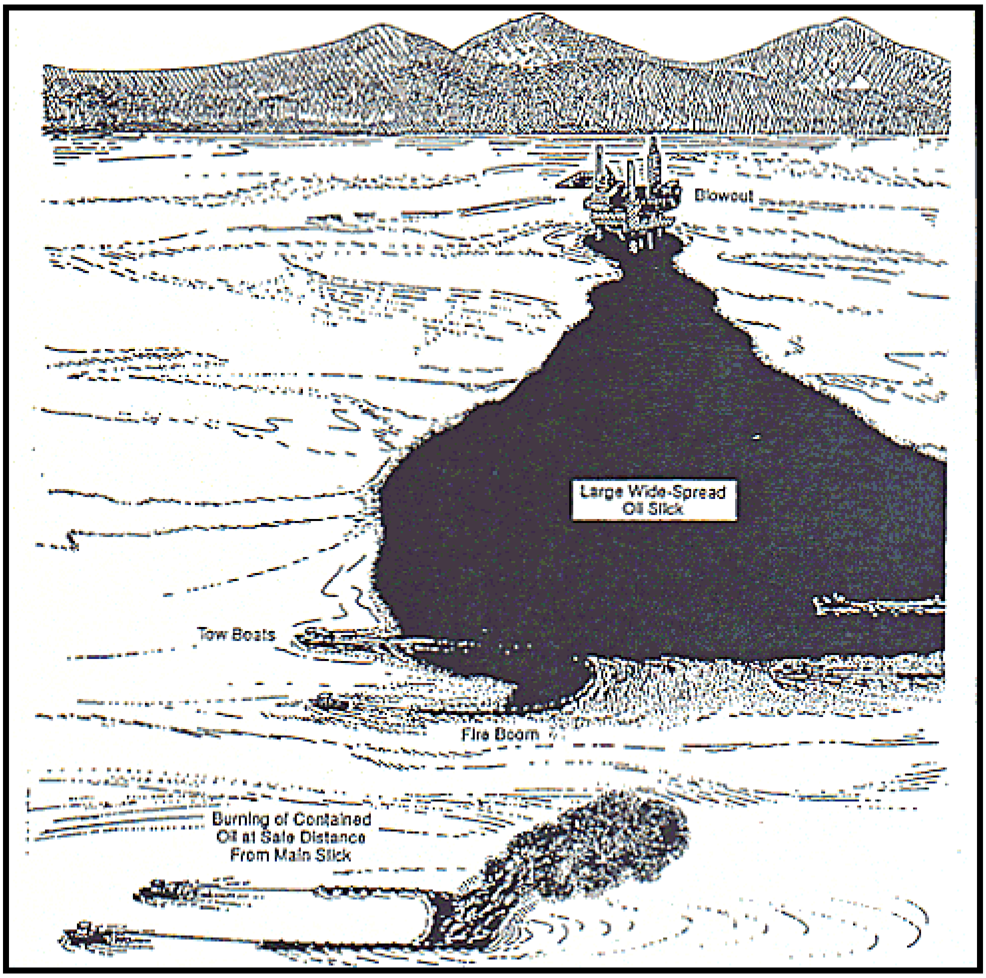

Figure 4 Collection, relocation and burning of oil that has already spread over large areas.

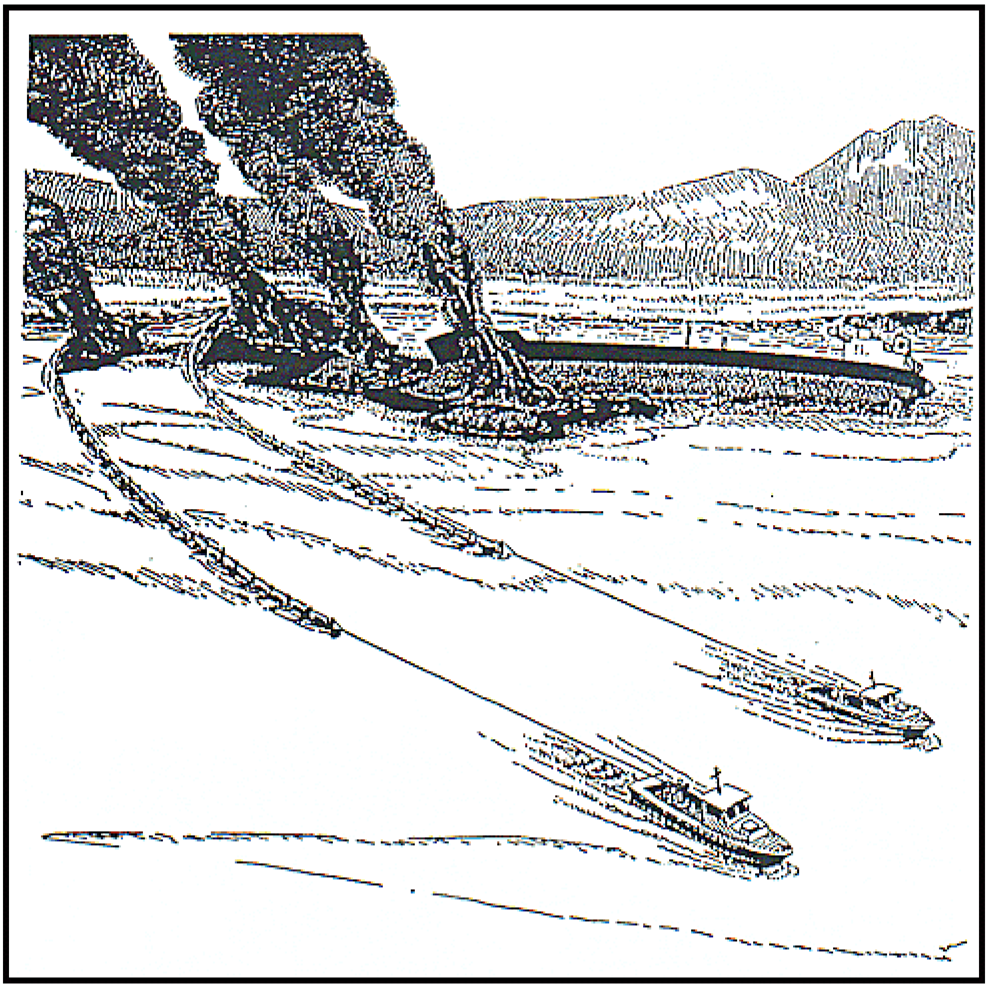

Figure 5   Controlled burning of oil trapped at shoreline.

In certain situations, spilled oil may remain relatively thick, for example if wind herds oil against a barrier (e.g., shorelines, ice floes, etc.); if oil collects in the lee of large vessels, islands, etc.; or simply if so much oil is released noto relatively calm water that a temporary “equilibrium thickness” of a few millimeters or more is achieved (Figure 7). Once a slick is ignited, natural thickening of the oil may be enhanced by the thermally induced wind that draws the oil from the outer edges of the slick toward the burning main body of the spill.

It is sometimes safer to let spilled flammable material disperse naturally in order to reduce the risk of fire and explosion at the spill site. On the other hand, the immediate containment of the spill may pose the least overall risk, even though a fire could result in the destruction of the nearest vessel(s), facilities, or equipment. In such cases, secondary fires from spreading burning oil could result in far greater losses if the source of spillage accidentally ignites and oil is allowed to flow freely away from the source.

Fire-resistant boom can be used as a floating fire-resistant barrier to limit the spread of an already burning or a potentially ignited oil slick. Such boom can be used to exclude burning oil from nearby boats, docks, and other facilities, and it can be used to contain burning oil for the application of fire-fighting foam.

4. SAFETY CONSIDERATIONS

As with all oil spill response techniques, the safety of personnel involved must be given the highest priority in any burn program, and a site- and spill-specific burn plan and safety procedures must be developed. All planning and operational personnel must thoroughly assess any potential exposure risks associated with the proposed burn. This risk assessment should include as a minimum:

- The expected size and duration of burn based on estimated oil volumes, burn rates, burn-area control measures, etc.;
- The location of the burn and any possible change in location due to currents, equipment failure, the towing of containment boom, etc. (this should include the possible movement of personnel, animals, boats, etc. to areas near the burn, resulting in possible exposure to excessive heat and/or combustion products);

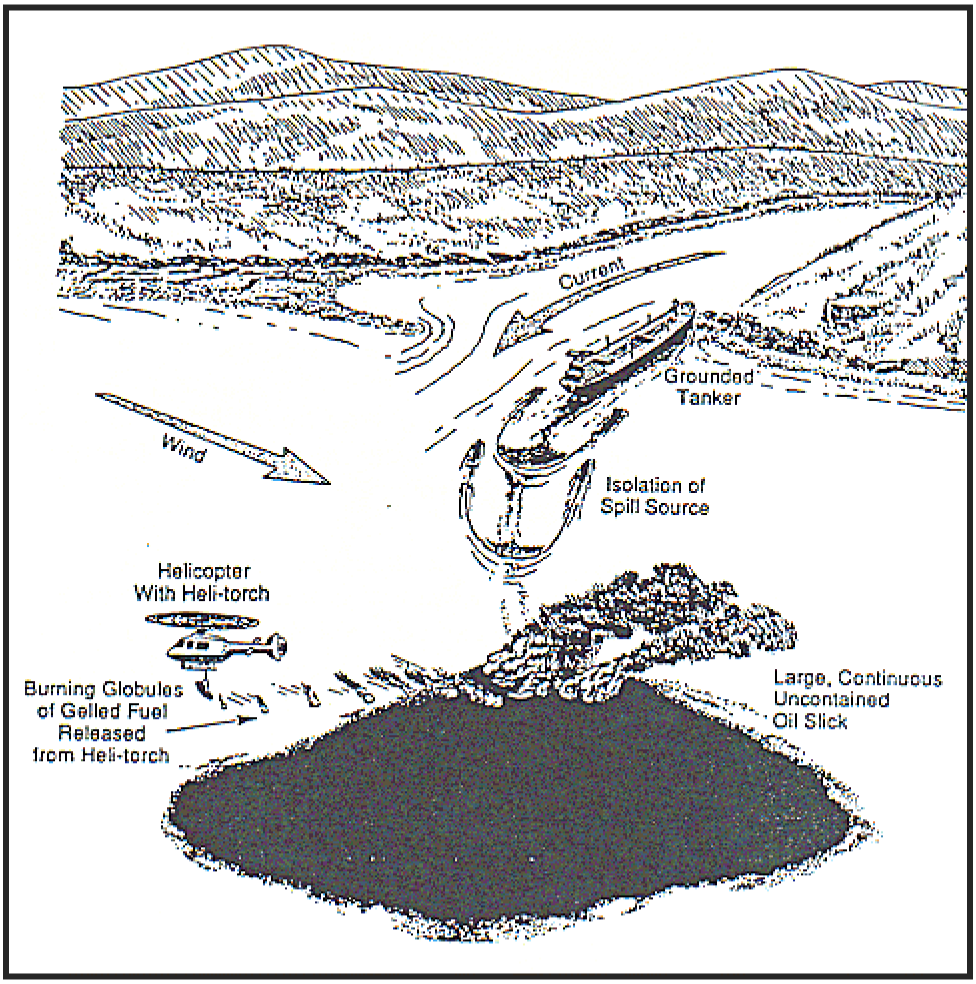

Figure 1 Burning of thick uncontained oil spill.

- The movement and duration of burn for any oil that might be released (accidentally or in response to an emergency) from within an area of controlled burning; and
- The location and type of fixed equipment/facilities (e.g., moored vessels, docks, bridges, etc.) that could conceivably be exposed to burning oil or heavy concentrations of combustion products.

Each individual involved in any capacity with controlled burning should complete classroom and hands-on training appropriate to his or her responsibilities. Standard fire safety procedures must be followed. Such procedures would include Heli-torch preparation and use guidelines, the provision of proper tow line for fire boom, the use of spotter aircraft, the positioning of support vessels upwind or sidewind to the burn, the monitoring of air quality where people are present, and the provision of adequate personal safety equipment.

5. SUMMARY AND CONCLUSIONS

For years, the response to major open-water oil spills has proven less than adequate because oil often spreads rapidly to enormous areas and is deposited over broad coastal regions. Even when containment and recovery systems can be mobilized in time, they are usually insufficient to deal with the very large volumes of recovered oil and water. Because of a general lack of preparedness and the inadequacy of mechanical equipment alone, organizations throughout the world are rethinking their contingency plans for major spill events. Increased emphasis is being placed on the use of non-mechanical response methods such as dispersant application and in-situ burning. Chemical dispersants, particularly when applied from aircraft, provide an effective means of accessing large spill areas even at remote locations. Contained controlled burning, while subject to many of the same constraints as contained mechanical recovery, can quickly and safely eliminate large quantities of oil efficiently, with minimal logistics support, and without the need for large temporary storage systems on location. Under the right conditions, burning can also be conducted in very shallow waters (for example, marshes and streams) where large recovery and storage systems could not operate.

The concerns about the environmental impacts of in-situ burning are often put to rest once it is realized that most of the oil being burned was originally intended for just that purpose (i.e., combustion in engines, furnaces, etc.) -- albeit in a less smoky manner. No net increase in the emission of carbon dioxide results, other products of combustion are for the most part minor in amount and rapidly dispersed, and a net benefit results from the destruction of many of the lighter volatile hydrocarbons that would have entered the atmosphere through evaporation had the slick been left on the water.

Neither burning, chemical dispersants nor mechanical cleanup, used individually or in concert with each other, will ever account for the removal of all oil spilled. No one technique should ever be discounted, however, because it is (or may be) only partially effective. In a major spill event every tool should be considered and used, if safe to do so, for the removal of as much oil as possible. Even if each of these response techniques only accounted for 10% to 15% of an offshore spill, man and nature would likely keep more than 50% of the oil from reaching shore.

NOTE

As with any operation involving work offshore with vessels and heavy equipment, in-situ burning can be dangerous if not properly conducted. This is particularly true because of the added variable of fire. However, systems and methods are available to conduct in-situ burning operations safely and efficiently. The reader is referred to a publication by the author for American Marine, Inc. entitled *In-Situ Burning Manual: An Economic Solution for Oil Spill Control* for much greater detail on in-situ burning as a spill response technique.

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