Open-water Response Strategies: In-situ Burning

What is in-situ burning?

"In-situ" is Latin for "In-place." In-situ burning involves controlled burning of oil that has spilled from a vessel or a facility, at the location of the spill. Typically, the oil is contained within a boom and ignited using a hand-held igniter or an igniter suspended from a helicopter. The burn will continue only as long as the oil is thick enough—usually about 1/10 of an inch or 2 to 3 millimeters. When conducted properly, in-situ burning significantly reduces the amount of oil on the water and minimizes the adverse effect of the oil on the environment.

Why conduct in-situ burning?

When a spill occurs it is best to minimize the spread of the oil slick and remove as much of the oil as possible at the site of the spill. In-situ burning may provide a response method to help achieve this goal. Under favorable conditions in-situ burning is a fast, efficient, and relatively simple way of removing spilled oil from the water. Furthermore, it greatly reduces the need for storage and disposal of the collected oil and the waste it generates. When an oil spill occurs in ice-covered water or in a marsh, in-situ burning may be the only spill response method available. In-situ burning, however, should complement, not exclude, other means of spill response. When possible, spill responders start mechanical recovery immediately, using booms, skimmers, and other equipment. They may also use dispersants if conditions allow it.

How is in-situ burning done?

On open water, in-situ burning is likely to be done by two boats towing a fire-resistant boom in a U configuration. The open end of the U is maneuvered through the oil slick and a "boomful" of oil is collected. The boom is towed away from the main slick and the oil is ignited. During the burning, the pooled boom slowly advances ahead of the current to ensure that the oil is concentrated at the back end of the boom and maintains maximum thickness. After the oil is burned, the process may be repeated for as long as in-situ burning is feasible.

When a spill occurs in a river and the current is not too swift (below one knot) a fire-resistant boom may be anchored across the river to collect the oil. When the oil layer in the boom is thick enough, the oil is ignited.

In both cases it is possible to stop the burn by releasing one end of the boom, or by towing it faster so that the oil is no longer contained.

In-situ burning has been done successfully on numerous occasions when oil was trapped in ice, or spilled into sensitive marshland. Unlike burning on open water, burning on land is more difficult to extinguish.

What are the limiting factors?

One of the disadvantages of in-situ burning is that any of a number of factors may prevent its use.

Environmental

Oil thickness

In order to burn on the water, oil has to be thicker than 1-2 millimeters. During combustion the oil vapors ignite and burn, rather than the liquid itself. About 2-3% of the heat generated by the combustion is returned to the oil layer where it causes additional vapors to escape and burn (Buist 1994). When the oil layer is thinner than 1-2 mm, the heat is lost to the water, not enough vapors are released, and combustion ceases.

Waves and wind

Experiments have shown that in-situ burning is possible only under relatively calm conditions. When winds are stronger than approximately 20 knots and waves are higher than 3 feet, burning becomes increasingly difficult because the oil cannot be contained in a boom and because it would rapidly emulsify due to wave action (Allen 1993).

Current

The same limitations that apply to ordinary booms apply to fire-proof booms. When the current is stronger than about one knot the boom cannot contain the oil, which splashes above the boom or escapes beneath it.

Emulsification

Emulsification occurs when crude oil spilled on the water takes in microscopic droplets of water. This usually requires mixing energy in the form of waves. When oil emulsifies its viscosity greatly increases, the total volume of "oily material" increases and most significantly for in-situ burning, ignition and combustion of the spilled oil become increasingly difficult. Water-in-oil emulsion of over 50% will preclude in-situ burning of even light crudes or refined products, while much less than that is required for heavier crudes. It is interesting to note that experiments with emulsion breakers applied to and mixed into the oil enable a mixture of 60% water in oil emulsion to ignite and burn in a fairly normal fashion (Buist, 1995).

Operational

Boom

The present open-water in-situ burning technique requires a fire-resistant boom. This boom needs to withstand the combined forces of heat exceeding 2,000˚F, wave action, and towing. The most prevalent boom is made of ceramic fireproof fabric; other booms are made of stainless steel material. Tests and real burns have shown that further improvements are needed in order to make fireproof booms viable for several consecutive burns. A program to test new booms and improve existing ones is underway (Walton 1997).

Booms are stockpiled in different locations around the nation where in-situ burning has been incorporated as a spill response technique. However, lack or insufficient amount of fireproof boom will limit or prevent the execution of open-water in-situ burning.

Human health

Human health has been one of the major concerns regarding in-situ burning. Essentially, in-situ burning converts the oil from a slick on the water into airborne gases and particulates that may travel long distances and potentially come in contact with people. To prevent possible human health impact, policies and guidelines have been established to limit in-situ burning to condition that will not risk the general population.

Natural resources

In general, any action that limits the spread of the spilled oil or treats it in-situ is seen as beneficial to wildlife and other natural resources. However, there may be situations in which in-situ burning may threaten natural resources. In-situ burning policies adopted by regions around the US incorporate provisions for protection of natural resources when conducting in-situ burning.

Approval

In-situ burning has a narrow window of opportunity. Approval for burning should be given either ahead of time (preapproval) or quickly on a case-by-case basis. If the approval process takes longer than it takes to prepare for the burn, the opportunity for using in-situ burning may be lost.

Emissions from in-situ burning

Studies of the emissions from in-situ burning have shown fairly consistent results. About 85 to 95% of the burned oil becomes carbon dioxide and water, 5 to 15% of the oil is not burned efficiently and is converted to particulates, mostly soot, and the rest, 1-3%, is comprised of nitrogen dioxide, sulfur dioxide, carbon monoxide, polynuclear aromatic hydrocarbons (PAH), ketones, aldehydes, and other combustion by-products (Ferek 1997). No "exotic" chemicals are formed. Rather, the burning of oil on water seems to be similar to burning the oil in a furnace or a car, with the exception that the burn is oxygen-starved and not very efficient, so that it generates ample amount of black soot particulates that absorb sunlight and create the black smoke.

Past burns

Many in-situ burns of oil were conducted over the years or occurred accidentally, in different types of environments. Most of them were successful in removing part or most of the spilled oil. A few examples are given below:

Burmah Agate

In November 1979, the tanker *Burmah Agate* carrying 14 million gallons of crude oil collided with a freighter near Galveston, Texas. The oil ignited and burned for more than a week, creating a large smoke plume. It is estimated that about 75% of the oil burned (Buist 1994).

Exxon Valdez

In March 1989 the tanker *Exxon Valdez* ran aground on Blight Reef in Prince William Sound, Alaska, spilling approximately 11 million gallons of North Slope crude oil. On the second day of the spill, in calm weather, between 15,000 and 30,000 gallons of the oil was collected and burned, using 150 meters of fireproof boom towed by two boats. This successful burn using a fireproof boom boosted the efforts to incorporate in-situ burning as a spill response method.

Kuwait

By far the largest in-situ burning to date occurred in 1991 in Kuwait, when the retreating Iraqi forces set ablaze about 700 oil wells. At the height of this environmental disaster, about 6 million barrels of oil were burned daily (Ferek 1997). It is estimated that more than a billion barrels of oil were burned over nine months until the fires were extinguished. The fires created a massive smoke plume that darkened the sky in the area for many months. When the flames subsided, it became apparent that the massive fires greatly reduced the amount of oil that actually spilled and polluted both the landscape and the marine environment, and that the long-lasting effects of the smoke plume were minimal.

San Jacinto River

Following massive floods, four pipelines containing gasoline, diesel fuel, light crude oil, and liquefied petroleum gas ruptured over the San Jacinto River near Houston in October 1994 and caught fire. The fire lasted for several days. When the floods subsided, a boom was anchored across part of the river to collect the oil escaping from the fire. The oil was ignited and burned in the boom for about 12 hours. Both the accidental and deliberate burning significantly reduced the extent of environmental impact (NTSB 1996).

Marsh burns

In recent years, in-situ burning has been conducted on land more often than on open water. In April 1993, spilled jet fuel was ignited in an ice covered marsh near Brunswick Air Force Base in Maine. After mechanical removal reached the limit of its efficiency, about 30,000 gallons remained in the marsh, and were almost completely burned. Pipeline spills were ignited both in Texas, near Copano Bay in January 1992 and at the Rockefeller Nature Refuge in Louisiana in March 1995. In both cases most of the oil was burned. Studies are being conducted to assess marsh recovery.

Human health concerns

One of the main objections for conducting in-situ burning was based on the concern that the smoke generated could affect the health of the general public downwind of the burn. The health and safety of the responders conducting the burn was also a consideration.

Responders

Safety hazards for in-situ burning operations are similar to those of ordinary skimming at sea, with the added hazards related to the combustion process. Several points are especially useful to keep in mind:

- A specific burn plan should be prepared in order to methodically address safety hazards, protection measures, training requirements, communication, and other operational elements that have to be considered for a successful and safe burning operation. A burn site safety plan should be included in the general burn plan.
- The burning should be controlled, and flashback to the source prevented. Great care must be taken so that the fire is controlled at all times.
- Ignition of the oil slick, especially by aerial ignition methods (such as the helitorch), must be well coordinated with neighboring vessels and be carefully executed. Proper safety distances should be kept at all times.
- In-situ burning at sea will involve several vessels working relatively close to each other, perhaps at night or in other poor-visibility conditions. Such conditions are hazardous by nature and require a great degree of practice, competence, and coordination.
- Response personnel must receive the appropriate safety training. Training should include proper use of personal protective equipment, respirator training and fit-testing, heat stress considerations, first aid, small boat safety, and any training required to better prepare them to perform their job safely.

Safety hazards are substantial and should be given due attention. Usually they pose a much greater risk to the responders than chemical exposure.

General public

In-situ burning generates mostly carbon dioxide and water, particulates, and small quantities of nitrogen oxides, sulfur dioxide, ketones, aldehyde, and other minor combustion gases. PAHs, some of which are suspected human carcinogens, are found in minute concentrations, adsorbed to the soot particulates. Studies on in-situ burning smoke components indicate that particulates in the smoke plume remain the only agent of concern more than a mile or two downwind. The gases created in the burn dissipate to background levels a short distance downwind, and the level of PAHs attached to the particulates is much below the level of concern (Fingas 1994). Public exposure to smoke particulates from the burn is not expected unless the smoke plume sinks to ground level. However, since the general public may include individuals sensitive to air pollutants their tolerance to particulates may be significantly lower than that of the responders.

Particulate size

Since 10 micrometers (µm) in diameter is the size below which particulates may be inhaled and become a burden on the respiratory system, scientists divide the particulate mass into “total” particulates, which include any size measurable, and “PM-10,” which is the fraction of particulates smaller than 10 µm in diameter.

Particulate size also plays a crucial role in determining how long they will be suspended in the air. Larger particulates (tens of µm in diameter) would precipitate rather quickly close to the burning site. Smaller particulates (ranging from a fraction of a µm to several µm in diameter) would stay suspended in the air for a long time and be carried over long distances by the prevailing winds. Particulates small enough to be inhaled (PM-10) are also the ones to remain suspended. If those particulates do not descend to ground level (where people are), they will not threaten the population downwind.

Particulate level of concern

The general public may be protected by minimizing exposure and conducting the burn only when conditions are favorable and exposure to particulates from the burn is below the level of concern. The National Response Team-recommended level of concern for the general public is 150 micrograms of particulates per one cubic meter of air, over a one hour period (NRT 1995). This level is much more conservative than the present legal requirement set at 150 microgram of particulates in a cubic meter of air, but averaged over 24 hours. In the process of adopting in-situ burning, the different regions around the country adopted the NRT's recommendation for a health-protective particulate level of concern.

Monitoring and modeling the smoke plume

The easiest and simplest way to monitor the smoke plume is by visual observation, which provides useful information on the plume direction and behavior. However, to try and assess the smoke component in the plume, instruments tethered from a blimp collected data on gases and particulate composition and concentration, while remote controlled helicopters took samples in the smoke, and a Light Detection and Ranging (LIDAR) instrument, which uses laser beams to detect particulate concentration in the plume was used from an aircraft in several test burns (Fingas 1994). These methods were very useful in providing information on the smoke composition and component concentrations, but they can't be used on a real-time basis to provide immediate feedback during the burn itself.

Real-time aerosol monitors are now available. They are small and portable, may be carried by hand and in a helicopter, and are easy to operate. Since they count particles by light scattering, their output is not as accurate as more traditional methods that weigh the particulates as they accumulate on a filter media. However, these instruments may provide useful real-time feedback during in-situ burning operations if population exposure to the smoke plume becomes an issue.

Modeling is another approach to estimating the concentration of particulates in the plume. Several models were developed, including a relatively simple model developed by NOAA, and ALOFT, a complicated model developed by the National Institute of Standards and Technology. Using information available on atmospheric conditions, burn parameters, and even terrain characteristics, this model, which is now available for use on a powerful PC, can predict the plume behavior and both ground and plume particulate concentrations over distance. The model has been used for several test burns, and was found to be reasonably accurate. Models are particularly useful for planning purposes and for situations in which direct air sampling is not possible.

Environmental Concerns

Burn residue

Generally, the composition of burn residue is similar to that of the original oil. The difference is that the residues have less volatile hydrocarbons with low boiling points, and are denser and more viscous than unburned oil.
Experience has shown that the burn residues may either float or sink. In a controlled test burn during the *Exxon Valdez* spill, an estimated 15,000 to 30,000 gallons of Prudhoe Bay crude oil were burned. Following this burn, about 300 gallons of “stiff, taffy-like burn residue that could be picked up easily” remained (Allen 1990).

During the 1991 explosion and burning of the tanker *Haven* off Genoa, Italy, burn residues sank. Reliable estimates of the amount of oil actually burned were not possible, but the tanker was laden with 141,000 tons of Iranian heavy crude, and very little remained in the wreck following the accident and fire. Moller (1992) reported that several 1991 surveys confirmed that there was sunken oil offshore and along the coast.

In other cases, the residues stay afloat while warm, but sink as they cool off. In a series of test burns in Prudhoe Bay, Alaska using Alaska North Slope crude, it was found that, as the residues cooled, some of it sank (Buist 1995). The sunken residues formed a brittle solid, while the residues that stayed afloat were semi-solid tar. It seems, therefore, that prompt collection of the residues can at least in some cases prevent the residues from sinking.

Direct temperature effect

Burning oil on the surface of the water could adversely affect those organisms at or near the interface between oil and water, although the area affected would presumably be relatively small. Observations during large-scale burns using towed containment boom did not indicate a temperature impact on surface waters. Thermocouple probes in the water during the Newfoundland test burn showed no increase in water temperatures during the burn (Fingas 1994). It appears that the burning layer may not remain over a given water surface long enough to change the temperature because the ambient-temperature seawater is continually being supplied below the oil layer as the boom is towed.

Water-column toxicity

Environment Canada coordinated a series of studies to determine whether in-situ burning caused water-column toxicity beyond that attributable to allowing the slick to remain on the surface of the water. While these studies centered on the Newfoundland in-situ burn field trials conducted in August 1993, they also included laboratory tests to investigate potential effects in a more controlled environment (Daykin 1994).

Results from the laboratory and field studies indicated that, although toxicity increased in water samples collected beneath oil burning on water, this increase was generally no greater than that caused by the presence of an unburned oil slick on water. Chemical analyses performed along with the biological tests reflected low hydrocarbon levels in the water samples.

Effect on surface microlayer

The surface of the water represents a unique ecological niche called the “surface microlayer,” which has been the subject of many recent biological and chemical studies. The microlayer, often considered to be the upper millimeter or less of the water surface, is habitat for many sensitive life stages of marine organisms, including eggs and larval stages of fish and crustaceans, and reproductive stages of other plants and animals. It is known that cod, sole, flounder, hake, anchovy, crab, and lobster have egg or larval stages that develop in this layer.

There is little doubt that in-situ burning would kill the organism in the area of the burn. However, when considering the small area affected by in-situ burning, the rare nature of this event, and the rapid renewal of the surface microlayer from adjacent areas, the long-term biomass loss is negligent (Shigenaka 1993).

Birds and mammals

In the wake of a major oil spill, any spill response method that would prevent the oil from spreading and impacting large areas is clearly advantageous for birds and mammals. During the *Exxon Valdez* spill thousands of birds were killed by the oil spreading hundreds of miles away from its source. Based upon our limited experience, birds and mammals are more capable of handling the risk of a local fire and temporary smoke plume than of handling the risk posed by a spreading oil slick. Birds flying in the plume can become disoriented and could suffer toxic effects. This risk, however, is minimal when compared to oil coating and ingestion, the result of birds' exposure to the oil slick.

The effect of in-situ burning on mammals is yet to be seen. It is not likely that sea mammals will be attracted to the fire, and the effect of smoke on marine mammals is likely to be minimal. Mammals, on the other hand, are adversely affected by oil ingestion and oil coating of their fur. Therefore, reducing the spill size by burning the spilled oil can reduce the overall hazard to mammals.

Once coated by oil, neither birds nor mammals have responded well to rehabilitation efforts, and although much has been learned and rehabilitation methods have greatly improved, the success rate of wildlife rehabilitation has been moderate at best.

Burning vs. Evaporation

Leaving the oil untreated has a deleterious effect on air quality. Spilled oil left untreated would evaporate at a rate that depends upon the type of oil, time elapsed from release, wind, waves, and water and air temperatures. The amount evaporated is substantial. The ADIOS oil behavior model developed by NOAA predicts that 33% of spilled Alberta Sweet crude would evaporate after 24 hours in 70˚F water and 10 knot wind, and after five days 43% would have evaporated. This evaporation pattern, similar in other oil types, emphasizes the need for quick action if in-situ burning is selected as the response tool.

The decision of whether to burn involves a tradeoff: burning the oil would reduce or eliminate the environmental impact of the oil slick and convert most of the oil to carbon dioxide and water. Burning, however, would generate particulates and cause air pollution. Not burning the oil would enable the slick to spread over a large area and affect the environment. Particulates would not be produced, but up to 50% of the oil would evaporate, causing a different kind of air pollution.

Waste generation

Review of the environmental impacts would not be complete without considering the waste an oil spill can potentially generate. It was estimated that 350 miles of sorbent boom was used during the first summer of the *Exxon Valdez* cleanup (Ferriere 1993), more than 25,000 tons of sorbent material of all kinds was sent to landfills, and oily water twice the volume of the oil spilled (from skimming a fraction of the oil) had to be treated (Fahys 1990). Enough energy was used that summer to support the energy needs of 11,000 people, power 1,300 boats of all sizes, and provide hot water equal to the needs of a city of 500,000 people (Ferriere 1993).

In-situ burning of oil is going to generate waste. Even the most efficient burning will leave a taffy-like residue that will have to be collected and treated or disposed of. Burning the oil at sea will not be as efficient as burning it in engines, furnaces, or power plants, and will generate a substantial amount of particulates. However, by minimizing the solid and liquid waste generated by beach cleanup, and by reducing the energy required to support the response operation, burning even some of the oil at sea is likely to reduce the overall waste generation of a spill.

Summary

Like any spill response method, in-situ burning can offer important advantages over other response methods in specific cases, and may not be advisable in others, depending upon the overall mix of circumstances.

Pros:

- In-situ burning can potentially remove large quantities of oil from the surface of the water with a relatively minimal investment of equipment and manpower.
- Burning may offer the only realistic means of spill response where logistics and environmental conditions preclude other options, such as spills in ice-covered water.
- In-situ burning may prevent or significantly reduce the extent of shoreline impacts, including exposure of sensitive natural, recreational, and commercial resources.
- Burning rapidly removes oil from the environment, particularly when compared to shoreline cleanup activities that may take months or even years.
- In-situ burning reduces storage and disposal requirements by converting the oil to gases and particulates that naturally disperse in the atmosphere. Residues left at the end of the burn need to be collected and disposed of, but they represent a small fraction of the initial oil volume.

- In-situ burning is versatile. It may be conducted on open water, ice-covered water, on rivers, on wetlands and marshes, and on dry land.

Cons:

- The method generates large quantities of highly visible smoke that may adversely affect human population downwind.
- In-situ burning pose risks to response personnel, and requires training, communication, and coordination.
- Burn residues may sink and affect natural resources. The longer-term effects of burn residues on exposed populations of marine organisms have not been investigated. It is not known whether these materials would be significantly toxic in the long run
- In-situ burning can be done only over a short period of time following a spill. It requires fast action and response. Furthermore, in-situ burning can be done only in relatively calm weather.
- As of this writing, all the booms currently tested have suffered from flaws. A sturdy, long lasting, effective, and relatively inexpensive fireproof boom is not yet available.

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