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Standard Guide for
In-Situ Burning of Oil Spills on Water: Environmental and Operational Considerations[1]

1. Scope

1.1 This guide covers the use of in-situ burning to assist in the control of oil spills on water. This guide is not applicable to in-situ burning of oil on land.

1.2 The purpose of this guide is to provide information that will enable spill responders to decide if burning will be used as part of the oil spill cleanup response.

1.3 This is a general guide only. It is assumed that conditions at the spill site have been assessed and that these conditions are suitable for the burning of oil. It is also assumed that permission to burn the oil has been obtained. Variations in the behavior of different oil types are not dealt with and may change some of the parameters noted in this guide.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definitions:*

2.1.1 *burn efficiency*—burn efficiency is the percentage of the oil removed from the water by the burning.

2.1.1.1 *Discussion*—Burn efficiency is the amount (volume) of oil before burning; less the volume remaining as a residue, divided by the initial volume of the oil.

2.1.2 *burn rate*—the rate at which oil is burned in a given area.

2.1.2.1 *Discussion*—Typically, the area is a pool and burn rate is the regression rate of the burning liquid, or may be described as a volumetric rate.

2.1.3 *contact probability*—the probability that oil will be contacted by the flame during burning.

2.1.4 *controlled burning*—burning when the combustion can be started and stopped by human intervention.

2.1.5 *fire-resistant booms*—devices that float on water to restrict the spreading and movement of oil slicks and constructed to withstand the high temperatures and heat fluxes of in-situ burning.

2.1.6 *in-situ burning*—use of burning directly on the water surface.

2.1.6.1 *Discussion*—In-situ burning does not include incineration techniques, whereby oil or oiled debris are placed into an incinerator.

2.1.7 *residue*—the material, excluding airborne emissions, remaining after the oil stops burning.

3. Significance and Use

3.1 This guide is primarily intended to aid decision-makers and spill-responders in contingency planning, spill response, and training.

3.2 This guide is not specific to either site or type of oil.

4. Background

4.1 *Overview of Oil Burning*:

4.1.1 In-situ burning is one of several oil-spill countermeasures available. Other countermeasures could include mechanical recovery, use of oil-spill dispersants, and leaving the oil to natural processes.

4.1.2 In-situ burning is combustion at the spill site without removing the oil from the water. Containment techniques may be used, however, to increase the thickness of the oil. The thickness of the oil slick is an important factor in the use of in-situ burning.

4.1.3 In-situ burning does not include incineration techniques whereby oil or oiled debris are placed into an incinerator.

4.2 *Major Advantages and Disadvantages of In-situ Burning*:

4.2.1 Advantages of in-situ burning include the following:

4.2.1.1 Rapid removal of oil from the water surface,

4.2.1.2 Requirement for less equipment and labor than many other techniques,

4.2.1.3 Significant reduction in the amount of material requiring disposal,

4.2.1.4 Significant removal of volatile emission components, and

4.2.1.5 May be the only solution possible, such as in oil-in-ice situations.

4.2.2 Disadvantages of in-situ burning include the following:

4.2.2.1 Creation of a smoke plume,

4.2.2.2 Residues of the burn must be dealt with,

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4.2.2.3 Time in which to ignite the oil may be limited,

4.2.2.4 Oil must be a minimum thickness to burn, which may require containment, and

4.2.2.5 The fire may spread to other combustible materials.

5. Environmental Considerations for Deciding to Use In-Situ Burning

5.1 *Air Quality*:

5.1.1 Several studies have been done of the air emissions resulting from in-situ burning. It has been found that the smoke plume consists largely of carbon and that toxic compounds are not created. The high temperatures achieved during in-situ burning result in efficient removal of most components of the oil. The thick, black smoke can be of concern to nearby human populations or ecologically sensitive areas. Since most soot precipitation occurs near the fire, this is the main area of concern. The smoke plume is, however, generally an aesthetic concern. In-situ burning should be avoided within 1 km upwind of either an ecologically sensitive or a heavily populated area, depending on meteorological conditions. No emissions greater than one fourth of the 1994 human health exposure limits have been detected at ground level further than 1 km from an oil fire. The values of the human health exposure limits vary with jurisdiction, and, thus, the appropriate documents should be consulted. The environmental and economic trade-offs of burning the oil, as opposed to contamination of the shoreline, must be considered.

5.1.2 Burning can be safely conducted near populated areas if there is sufficient air turbulence for mixing, and in the absence of a low-level atmospheric inversion.

5.2 *Water Quality*—Measurements show that burning does not accelerate the release of oil components or combustion by-products to the water column. Highly efficient burns of heavy oils may form a dense residue that sinks.

5.3 *Wildlife Concerns*—Although no specific biological concerns related to the use of in-situ combustion have been identified to date, benthic resources may be affected by sunken oil burn residue.

6. Operational Considerations for In-situ Burning

6.1 *Safety Considerations*—The safety of the proposed operation shall be the primary consideration. Secondly, the burning operation shall not result in unintentional flashback to the source of the oil, for example, the tanker or the production platform. The third consideration is the spread of the fire to other combustible material in the area, including trees, docks, and buildings. Flashback and fire spread can often be prevented by using containment booms to tow away the oil to be burned. A fourth consideration is the safety of the ignition operation, which is often done from helicopters, and the safety of the boom tow operation must be ensured.

6.2 *Safety Monitoring and Control Requirements*—The operation must be monitored to meet safety requirements. Burning shall be monitored to ensure that fire may not spread to adjacent combustible material. Situation-specific contingency methods of extinguishing, such as boats with fire monitors, shall be available. In towed-boom operations, it has been proposed that the fire may be extinguished by increasing the tow speed so that the oil is entrained in the water. Other options for controlling the fire or the burn rate might include releasing one side of the oil containment boom or slowing down to reduce the encounter rate.

6.3 *Oil Thickness*—Most oils can be ignited on a water surface if they are a minimum of 2 to 3 mm thick. Once ignited, the oils will burn down to a thickness of about 1 mm. Physical containment, such as with oil-spill containment booms, is usually necessary to achieve the minimum thicknesses required. Specific information on this is provided in the appendix.

6.4 *Oil Type and Condition*—Highly weathered oils will burn, but will require sustained heat during ignition. Oil that is emulsified with water may not burn. Not enough data are available to determine water-content levels that limit ignition. Indications are, however, that stable emulsions which typically contain about 70 % water cannot be ignited and that oils containing less than about 25 % water will burn. Treatment with chemicals to remove water before burning can permit ignition.

6.5 *Wind and Sea Conditions*—Strong winds may extinguish the fire. In-situ burning can be done on the sea with winds less than about 40 km/h (about 20 knots). High sea states are not conducive to containment by booms. Wave heights of 1 m or more may result in splash-over of the oil.

6.6 *Burn Efficiency*—Burn efficiency, which is the percentage of oil removed by burning, has been measured as high as 99 % for contained oil. Burn efficiency is largely a function of oil thickness and flame-contact probability. Contact probability is the probability that oil will be contacted by the flame during burning. Inhomogeneous oil distribution on the surface can result in an incomplete burn. This can result as the flame may be extinguished over a patch that is not thick enough to burn, while adjacent patches that are thick enough will subsequently not be burned. Contact is usually random and is influenced by wind speed and direction and can be controlled by human intervention in some cases.

6.7 *Burn Rate*—Oil burns at the rate of about 3 mm/min, which means that the surface of the oil slick regresses downwards at the rate of 3 mm/min. This translates to a rate of about 5000 L/m^2/day (or 100 gal/ft^2/day). Burn rate is relatively independent of physical conditions and oil type. Using these values, it is possible to calculate the rate of burning in booms and in other burn operations.

6.8 *Containment*—Oil slicks must be a minimum of 2 to 3 mm thick to be ignited. As oil naturally spreads quickly to much thinner slicks than this under normal circumstances, physical containment is generally necessary for burning. Fire-resistant booms are commercially available for this purpose. While these booms can be used in a variety of configurations, they are best used in a catenary mode and towed at speeds less than 0.35 m/s (0.7 knots). At speeds greater than this, oil is lost under the boom by entrainment. Slicks can sometimes be naturally contained by ice or against shorelines.

6.9 *Ignition*—Slicks can be ignited with a variety of devices. Enough heat must be supplied for a sufficient length of time. Weathered oils generally require a longer heating time to ignite.

6.10 *Residue Cleanup*:

6.10.1 Residue is the material remaining after the oil stops burning. Residue is similar to a highly weathered oil, depending on the burn conditions. It is viscous and often highly adhesive. Highly efficient burns result in heavier and denser residue. These residues may actually be more dense than sea water.

6.10.2 Floating residue can be removed manually with sorbents, nets, or similar equipment.

7. Summary

7.1 In-situ burning is a viable countermeasure that has the potential to quickly remove large amounts of oil. The air emissions of in-situ burning are below health and environmental concern levels at nominal distances from the combustion source.

8. Keywords

8.1 fire-resistant booms; in-situ burning; oil-spill burning; oil-spill containment; oil-spill disposal

APPENDIX

(Nonmandatory Information)

X1. INTRODUCTION TO THE IN-SITU BURNING OF OIL SPILLS

INTRODUCTION

In-situ burning has been used as an oil-spill countermeasure around the world **(1,2)**.[2] Recently, extensive research has been conducted on the many facets of burning oil **(3,4,5)**. The emissions from and basic principles of oil-spill burning are now relatively well-understood.

X1.1 Basic Principles of Burning Oil

X1.1.1 Oil slicks can be ignited if they are at least 2 to 3 mm thick and will continue to burn down to slicks of about 1 to 2 mm thick **(6)**[2]. These thicknesses are required because of heat transfer. Sufficient heat is required to vaporize material for continued combustion. In a thin slick, most of the heat is lost to the water, vaporization is not sustained, and combustion ceases.

X1.1.2 Containment is usually required to concentrate oil slicks so that they are thick enough to ignite and burn **(7)**. Fire-resistant containment booms can be used to keep fire from spreading back to the spill source, such as an oil tanker **(8)**. Burning in situ without the benefit of containment booms can be undertaken only if the oil is thick enough (2 to 3 mm) to ignite. For most crude oil spills, this only occurs for a few hours after the spill event unless the oil is confined behind a barrier. Oil on the open sea spreads rapidly to equilibrium thicknesses. For light crude oils, this is about 0.01 to 0.1 mm, for heavy crudes and heavy oils, this is about 0.05 to about 0.5 mm.

X1.1.3 Oil can be contained by natural barriers. For example, ice has been shown to serve as a natural boom. Several successful experiments and burns of real spills have shown that burning is a proven countermeasure for spills in ice **(4,9)**. Spills have occasionally been contained by shorelines. Burning could be applied in these instances, if the shoreline is remote and no combustible materials such as trees and docks are nearby.

X1.1.4 It is uncertain whether oil that is completely emulsified with water can be ignited. Oil containing some emulsion can be ignited and burned **(10)**. During the successful test burn of the Exxon Valdez oil, some patches of emulsion were present (probably less than 20 %) and this did not affect either the ignitability or the efficiency **(11)**. It is suspected that fire breaks down the water-in-oil emulsion, and thus water content may not be a problem if the fire can be started. There is inconclusive evidence at this time on the water content at which emulsions can still be ignited. One test suggested that a heavier crude would not burn with about 10 % water **(10)**, another oil burned with as much as 50 % **(12)**, and still another burned with about 70 % water **(13)**. One study indicated that emulsions may burn if a sufficient area is ignited **(13)**. Further studies indicate that stable emulsions will not burn but oil containing less than 25 % water can be ignited. Emulsions may not be a problem because chemical de-emulsifiers could be used to break enough of the emulsion to allow the fire to start.

X1.1.5 Most, if not all, oils will burn on water if slicks are thick enough. Except for light-refined products, different types of oils have not shown significant differences in burning behavior. Weathered oil requires a longer ignition time and somewhat higher ignition temperature **(12)**.

X1.1.6 Burning efficiency is the amount of oil before burning, less the volume left as residue, divided by the initial volume of the oil. The amount of soot produced is usually ignored in calculating burn efficiency. Efficiency is largely a function of oil thickness. Oil thicker than about 2 to 3 mm can be ignited and burns down to about 1 to 2 mm **(6,14)**. For example, a slick of 2 mm burning down to 1 mm yields a maximum efficiency of 50 %. A pool of oil 20 mm thick burns to approximately 1 mm, yielding an efficiency of about 95 %. Current research has shown that other factors such as oil type and low water contents only marginally affect efficiency **(4)**.

X1.1.7 The residue from oil-spill burning is largely unburned oil with some lighter or more volatile products removed

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[2] The boldface numbers in parentheses refer to a list of references at the end of this guide.

(15,16). Highly efficient burns of some types of heavy crude oil may result in oil residue that sinks in sea water.

X1.1.8 Most oil pools burn at a rate of about 3 mm/min **(17)**. This means that the depth of oil is reduced by 3 mm/min. As a rule of thumb, oil burn rate is about 5000 L/m^2/day (or about 100 gal/ft^2/day). Several tests have shown that this does not vary significantly with oil type and weathering. Emulsified oil, due to its water content and thus reduced spreading rate and the increased heat requirement of the water, may burn slower.

X1.1.9 Studies conducted in the last ten years have shown that the type of ignition device is relatively unimportant, however, heavy oils require longer heating times and a hotter flame to ignite than lighter oils. Many types of ignition sources can supply sufficient heat for a sufficient length of time. A number of simple devices consisting of flotation and propellant have been developed **(18-22)**. A helicopter-slung device that dispenses packets of burning, gelled fuel is the only commercial unit available at this time. Actual burns at some incidents and experiments have been ignited using much less sophisticated means including lighting oil-soaked paper and sorbent.

X1.2 Emissions from Burning

X1.2.1 The atmospheric emissions of concern include PAHs (polyaromatic hydrocarbons), volatile organic compounds, oxygenated compounds, metals, particulate matter, and gases.

X1.2.2 The PAHs have been measured in soot particles and as gaseous emissions at several test spills **(15-17,23-25)**. Gaseous emissions were found to be negligible. The soot from several experimental burns has been collected and the PAH content measured. In all cases, the quantity of PAHs is less in the soot and residue than in the originating oil. All crude oils contain PAHs, varying from as much as 1 % down to about 0.001 %. These PAHs are burned to fundamental gases, except for those left in the residue and those on the soot. Studies have shown that PAHs are produced in great abundance at temperatures of 600 to 800°C. At combustion temperatures higher than this, fewer and fewer PAHs are produced. In-situ oil fires are known to reach temperatures of up to 1300°C. One overall finding is that most compounds of concern are associated with the particulate matter, which is largely precipitated downwind from the burn. The deposition is approximately square root with distance; little is carried far from the site. In summary, PAHs are not a serious concern in assessing the impact of burning oil.

X1.2.3 Volatile organic compounds (VOCs) are organic compounds that have a sufficiently low vapor pressure to be gaseous at normal temperatures. The emission of volatile compounds was measured at several test burns **(15,16,26)**. It was found that emissions were very high for many of the compounds measured. About 70 compounds were detected and many of these were at concern levels directly downwind of the fire. Tests of emissions for these same compounds without burning, however, showed higher levels in most cases.

X1.2.4 Burning nearly always produces partially oxidized materials. In the case of oil, many of these materials are alcohols, aldehydes, ketones, and similar compounds. Extensive testing at one burn site showed that low quantities of these compounds were present downwind, but at well below health concern levels and, in fact, at near ambient levels.

X1.2.5 Crude and residual oils contain metals such as vanadium, chromium, and nickel in the range from 10 to 40 ppm. While the fate of these metals during the combustion process is uncertain, they appear to be concentrated in the residue. Measurements during a series of experimental burns have shown the metal content in the soot to be below detection level **(15,16)**.

X1.2.6 The most obvious atmospheric emission is particulate matter, smoke, or soot. The quantity of soot produced by in-situ oil fires is not well established. Direct measures in small pan burns result in soot production values of 0.7 to 3.5 % for crude oil and about 11 % for diesel fuel. No measurement techniques are available at this time for large-scale burns, however, estimates range up to 15 % **(27,28)**. These estimates are complicated by the fact that particulates precipitate from the smoke plume. The proportion of the soot that consists of respirable particles (less than 10 µm in diameter) is a relatively low value at ground level. Respirable particles measured at ground level are below concern levels several hundred metres downwind **(16)**. A typical exposure limit is 150 µg/m^3, (8-h average).

X1.2.7 The combustion of oil reduces the starting materials to fundamental gases. Most emissions are carbon dioxide, which have been measured and rarely exceed five times the background levels **(16,20,29)**. This is not a health concern. Levels of carbon monoxide have been measured and found to be near measurement thresholds and thus well below health-exposure levels. Sulfur dioxide emissions are usually much lower than indicated by the sulfur content of the oil **(20)**. Sulfur compounds in oil range from about 0.1 to 5 % of the oil weight. Nitric oxides have not been detected as a result of in-situ combustion of oil **(15,16)**.

X1.2.8 One concern about the burning of crude oil is the formation of new toxic compounds. A study was conducted in which soot and residue samples were extracted and “totally” analyzed in various ways. While the study was not conclusive, no compounds of the several hundred identified were of serious environmental or health concern **(15)**. The soot analysis revealed that the bulk of the material was carbon and that all other detectable compounds were present on this carbon matrix in abundances of parts-per-million or less. The most frequent compounds identified were aldehydes, ketones, esters, acetates, and acids, which are formed by incomplete oxidation of the oil. Specific analysis was performed for the highly toxic compounds, dioxins and dibenzofurans. Results of this analysis were negative—including those for oils burned on salt water **(15)**.

X1.2.9 The burning process leaves a burn residue. Studies show that the residue is largely composed of oil with little removed other than some of the more volatile materials **(15,16)**. It appears to be the same as weathered oil of the same type. The residue contains PAHs at lower concentrations than the starting oil, although it may also contain metals at a slightly higher concentration.

X1.2.10 The temperature to which the water body is raised has been another concern **(5,17)**. Measurements during recent burn trials show no significant increase in water temperature, even in shallow, confined test tanks. Thermal transfer to the water is limited by the insulating oil layer and is actually the mechanism by which the combustion of thin slicks is extinguished.

X1.2.11 Water samples under burning oil have been analyzed in four cases **(15,16)**. No organic compounds were detected.

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