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Standard Guide for In-Situ Burning of Oil in Ships or Other Vessels[1]

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1. Scope

1.1 This guide covers the use of in-situ burning directly in ships and other vessels. This guide is not applicable to in-situ burning of oil on sea or land.

1.2 This guide is applicable to situations in which the vessel and cargo are not salvageable. After the burn, the vessel will never be salvageable. It is intended that the in-situ burning of oil spills in ships be a last resort option.

1.3 The purpose of this guide is to provide information that will enable spill responders to decide if burning will be used to remove oil from stranded ships or other vessels.

1.4 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 permissions to burn the oil have 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.

1.5 This guide is one of several related to in-situ burning.

1.6 There are many safety concerns associated with in-situ burning of oil in ships. These include the unsafe nature of the wrecked vessel and the use of explosives.

1.7 *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. Referenced Documents

2.1 *ASTM Standards:*[2]

F1788 Guide for In-Situ Burning of Oil Spills on Water: Environmental and Operational Considerations

F1990 Guide for In-Situ Burning of Spilled Oil: Ignition Devices

3. Terminology

3.1 *Definitions:*

3.1.1 *burn rate, n*—the rate at which oil is burned in a given area. 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.

3.1.2 *burn efficiency, n*—burn efficiency is the percentage of the oil removed from the water by the burning. This is the amount (volume) of oil before burning; less the volume remaining as a residue, divided by the initial volume of the oil.

3.1.3 *coking, n*—coking is the formation of coke, a hardened charcoal-like material. Coke is often formed when a hydrocarbon such as oil is heated in absence of sufficient oxygen to burn completely.

3.1.4 *contact probability, n*—the probability that oil will be contacted by the flame during burning.

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

3.1.6 *eruption, n*—sudden upwelling of boiling oil in a tank due to specific area heating.

3.1.7 *fire-resistant booms, n*—devices which 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.

3.1.8 *in-situ burning, n*—use of burning directly on the water surface. In-situ burning does not include incineration techniques, whereby oil or oiled debris are placed into an incinerator.

3.1.9 *in-situ burning in ships, n*—use of burning on or in a ship.

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

3.1.11 *salvageable, adj*—a condition of the vessel such that it is economical and feasible to recover, refurbish and return to operation or to re-use portions of the vessel.

3.1.12 *seaworthy, adj*—a condition of the vessel such that it is fit and safe for sea voyage.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

4. Significance and Use

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

4.2 This guide is general and site conditions can change the situation considerably.

5. Background

5.1 *Overview of Oil Burning*—In-situ burning is one of several oil spill countermeasures available. The thickness of the oil is an important factor in the use of in-situ burning (see Guide F1788). The burning of oil in ships is implemented to remove oil from stranded or derelict ships to minimize the release of oil.

5.2 *Major Advantages and Disadvantages of Burning in Ships*

5.2.1 *Advantages of In-Situ Burning Include:*

5.2.1.1 May provide a net environmental benefit by quickly reducing the potential for oil release into the marine environment;

5.2.1.2 In remote locations it may be the only feasible solution;

5.2.1.3 A significant reduction in the amount of material requiring disposal;

5.2.1.4 A significant removal of volatile emission components;

5.2.1.5 Removal of oil from the ship.

5.2.2 *Disadvantages of Burning in Ships Include:*

5.2.2.1 The fire will weaken the ship hull and the ship could break up, releasing oil or residue;

5.2.2.2 Creation of a smoke plume;

5.2.2.3 Residues of the burn may be problematic;

5.2.2.4 The ship may have to be prepared such as by the use of explosives to ensure that the oil is presented to the burn and that there is sufficient ventilation;

5.2.2.5 The fire could spread to other combustible materials.

6. Limitations to Burning in Ships

6.1 *Access to Oil*—The oil must be accessible to ignition and accessible to air. Explosives are used to allow oil to flow from tanks to spaces where it will be burned and to increase ventilation area. This should be conducted by salvage and explosive experts. Typically, the planned burn would take place in the ship's hold(s) and explosives would be used to open passage from lubrication and fuel tanks to the hold. Lubrication and fuel tanks generally do not have sufficient exposure to the air to allow for burning.

6.2 *Ventilation*—Oxygen from air is necessary for burning. Studies have shown the area of ventilation is a critical regulating factor in the burning of oil directly on ships and in other confined spaces. The rate of burning is generally calculated based on the area of ventilation openings in the case of low wind situations. Studies have shown that top and side openings combined will yield better ventilation than top openings alone. The presence of two openings allows for air circulation over the area of fire. Small scale studies have shown that a minimum of 10 % ventilation is needed to prevent extensive coking. The 10 % refers to the area of ventilation compared to the surface area of oil available to burn. An area of more than 20 % ventilation has been shown to result in little coking during test burns.

6.3 *External Wind Speed*—External winds assist in providing additional ventilation, despite the semi-closed conditions that may exist. Burn efficiency increases and prevention of coking will also be a positive result of higher wind conditions. One study showed a three-fold increase in burn rate with wind increase from 0 to 11 m/s.

6.4 *Coking*—Coking is the formation of a hard, carbonaceous material during burning in a low oxygen environment. Coking is more prevalent with heavy residual oils. If coking occurs, the burn rate slows considerably as coke itself burns poorly, if at all, and the coke would prevent the flame from contacting oil under it. Coking is prevented by having sufficient ventilation.

6.5 *Ability to Ignite*—A consideration for in-ship burning is the ability to ignite the oil. There are some oils which are difficult to ignite and which may not sustain combustion (see Guide F1990). Successful ignition will depend on the type of oil, degree of ventilation, heat of ignition and length of time that ignition must be applied. Heavier oils will require application of heat for at least several minutes. Ventilation is required to sustain efficient combustion. The burning of the ignitor will deplete the oxygen in a given area if there is insufficient ventilation. Heavy bunker fuels have been successfully ignited in ships' holds using diesel fuel as a primer. A layer of 2 mm of diesel fuel has been shown to be sufficient during test burns.

6.6 *Eruption*—During the burn process, some localized oil may become super-heated. When the heating is sufficient, flash evaporation of a component of this oil may occur and the surrounding boiling oil can erupt upwards towards the top ventilation port. This could result in oil being splashed onto other parts of the vessel or sea. This phenomenon has been observed in test situations with crude oil.

7. Operational Considerations for Burning in Ships

7.1 *Safety Considerations*—The safety of the proposed operation will be the primary consideration. The vessel should be stable and relatively stationary during the preparation and burn phases. The operation should only be contemplated if the operation will not result in flashback to other sources of fuel. The fire should be prevented from spreading to other combustible material in the area, including trees, docks, and buildings. Situation-specific contingency methods of extinguishing or protection should be available. Further, escaping oil could pose a risk. The possibility that burning oil may erupt should be considered.

7.2 *Effects on the Ship's Structure*—Preparation of the vessel for burning by using explosives and subsequent burning of the oil will weaken the ship's structure. Burning in ships should be considered only if there is no potential for future salvage of the vessel or if the trade-off between future salvage potential and removing the oil is favorable. The use of explosives and burning may weaken the structure sufficiently to result in breakup of the vessel. A breakup may result in the release of oil. Salvage experts and experts on ship design should be consulted where possible, before proceeding with the preparation for ignition and burn. They should also be consulted after the burn regarding options to deal with the remaining vessel. The vessel may not be seaworthy, towable or even in condition to allow ship-breaking in place.

7.3 *Oil Thickness*—Most oils can be ignited on a surface if they are a minimum of 2 to 3 mm thick. This is generally not a concern in ships as sufficient oil may be available.

7.4 *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. Guidance on ignition is given in Guide F1990.

7.5 *Wind Conditions*—Winds will assist in providing additional ventilation, despite the semi-closed conditions that may exist. Increased burn efficiency and prevention of coking will also be a positive result of higher wind conditions. Wind direction should be a concern and local authorities should be consulted about the possibility of smoke plumes (see Guide F1788). At high wind conditions, the operation may be less safe for reasons including ship movement, getting personnel on decks, applying ignition devices and secondary fires.

7.6 *Burn Efficiency*—Burn efficiency in a confined area such as a ship's hold will vary and has been measured as high as 97 % for crude oil, but typically may be only 60 %.

7.7 *Burn Rate*—Most lighter oils burn at the maximum rate of about 3.75 mm/min. This translates to a rate of about 5000 L/m^2/day (or 100 gal/ft^2/day). Testing on heavy oils shows that the burn rate may be lower, as low as 1 mm/min or about 1200 L/m^2/day (or 25 gal/ft^2/day). Burn rate is relatively independent of physical conditions except for ventilation and high winds. In the case of high winds, the burn rate is independent of ventilation opening if it is greater than 10 %. With less ventilation, the rate will be less. Using these values, it is possible to calculate the rate of burning in the ship spaces. The area that is used for the calculation is the area of ventilation opening, not the area of the oil surface.

7.8 *Ignition*—Oils can be ignited with a variety of devices which are described in Guide F1990. Enough heat must be supplied for a sufficient length of time. Heavy fuel oils generally require a longer heating time to ignite. Ignition may also occur as a result of the explosives used to prepare the ship for burning.

7.9 *Back-up Containment*—The operation may release oil into the water or shore on which the hull is located. In some locations, a fire-resistant boom may be deployed around the vessel to contain any releases and to protect other combustible materials from the burning oil (see Guide F1788). If oil is released from the hull, it may be ignited.

7.10 *Residue*—The residue from efficient burns is a highly viscous liquid or even solid (see Guide F1788). It may sometimes have a density greater than water. Tests show that residue is relatively non-toxic to aquatic species.

8. Summary

8.1 Burning is a viable countermeasure that has the potential to remove oil from a stranded hull. The technique has been used with favourable results.

8.2 Burning in a ship is a last-resort method as the combustion heat weakens the ship structure. This heat may be sufficient to result in catastrophic structure failure and subsequent release of oil and residue.

9. Keywords

9.1 burning in ships; in-situ burning; oil spill burning; oil spill disposal; oil spill response; ship destruction

APPENDIXES

(Nonmandatory Information)

X1. EXPERIMENTAL STUDIES

X1.1 Diederichsen and co-workers (**1**)[3] conducted a number of small experiments using an Arabian crude oil and some IFO 80 in small scale (up to 6 by 6 m). It was concluded that there were three major factors for burning in enclosed tanks:

X1.1.1 Scale size,

X1.1.2 Ventilation,

X1.1.3 Coking. Coking is the result of oxygen-deficient burning and significantly slows the burn rate.

X1.2 An equation was developed for relating the burn rate to the maximum rate and dimensions of the container:

$$R = R_\infty \left((S - 0.12)/S \right)^2 \quad \text{(X1.1)}$$

where:

R = the actual burn rate,
R_∞ = the maximum burn rate, and
S = the side (horizontal) dimension of the square burn box in metres.

X1.3 A table showing maximum burn rate as function of wind speed and ventilation was provided as based on the experiments conducted. See Table X1.1.

X1.4 These numbers compare to the 1 to 3.75 mm/min burn rates generally used in the oil spill response (**2**). It should be noted that Eq X1.1 applies if the ventilation area is 11 % or greater of the oil surface area. Diederichsen and co-workers (**3**) also conducted a single burn of 175 tons of crude oil in a tank

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

TABLE X1.1 Maximum Burn Rate as Function of Wind Speed and Ventilations

	Wind Speed (m/s)		
	0	6	11
Percent of Venting	R_∞ in mm/min		
11	1.3	3.2	4.4
22	2	3.2	4.5

6 m long and two vents—one in the roof and one in the side. Some of the results are given as well in the discussion above, but a useful rule of thumb is given as: burning rate (mm/hour):

$$R = (67 + 17 \cdot W) \quad \text{(X1.2)}$$

where:

W = the wind speed in m/s.

X1.5 It is important to note here that the external wind speed had a significant effect on the burn rate. The effect of having both a side and top vent was not quantified at this stage.

X1.6 Diederichsen and co-workers (**4**) also studied the burning rate of crude oil in model tanks of four sizes, the largest being of an area, 360 m^2. One side vent and one top vent were used in each trial. The tanks were water-cooled on the bottom and one side to simulate sea condition effects on an actual tanker. The effects of wind were measured for the three smaller tanks using still air and blowers to simulate up to 11 m/s winds. Variations of burning rates with tank size, vent openings and wind velocity were measured. It was concluded that 97 % of the crude oil in the holds of stranded tankers could be burned under ideal conditions. Neither the rate nor the amount burned would appear to be increased by other measures taken. The residue was very heavy. The conditions needed for the burn are that holes of at least 10 % of the cross sectional area of the tank are needed both in the top and side of the tank. In this study equal ventilation areas were provided on the top and side. During the course of burning some of the fuel erupted and sprayed through the openings. The authors did not assign a specific cause for this, but suggested it might be due to local heating and then flash evaporation. The maximum burn rate was found to be 3.75 mm/min identical to the many other studies on burn rates (**2**). The burn rate was generally found to be:

$$R = 3.75\,((S - 1.2)/S)^2 \quad \text{(X1.3)}$$

where:

R = the burn rate in mm/min, and
S = side dimension in metres.

X1.7 The effect of wind speed on the rate can be given as:

$$R = (1.3 + 0.28 \cdot W) \quad \text{(X1.4)}$$

where:

W = wind speed in m/sec.

X2. THEORETICAL STUDIES

X2.1 Epstein (**5**) developed a model for the burning of material in enclosed spaces such as ships and after extensive development provides the following relationship:

$$m_{F,\max} = \frac{M_{F\rho\infty} Q_{\infty,\max}}{Mo_2 n}\left(Yo_2,\infty - Yo_2\right) \quad \text{(X2.1)}$$

where:

$m_{F,\max}$ = the maximum mass burning rate,
$M_{F\infty}$ = the molecular weight of the fuel,
Mo_2n = the molecular weight of oxygen,
n = the number of moles of oxygen per mole of fuel,
Y = the number of oxygen mass fractions entering and leaving the enclosure, and
$Y\infty$ = the maximum amount of oxygen needed, therefore the last term in the equation is the oxygen deficit.

X2.2 Substituting the average molecular weight of a medium crude oil and assuming that the vent is small, the following equation is derived:

$$Q_{\max} = 5.6 \times 10^{-3}\, D^{2.5} \quad \text{(X2.2)}$$

where:

$Q_{\max}$ = the maximum burn rate in kg/sec, and
D = the hole diameter in m.

X2.2.1 This rate, calculated by Eq X2.2, compares to the 3.75 mm/min rate typically taken for burning crude oils (**2**). The estimate given in Eq X2.2 is mid-range between the rates noted in this guide.

X3. ACCIDENTAL FIRES IN SHIPS

X3.1 The Atlantic Empress collided with the Aegean Captain in the Atlantic (**6**). The Atlantic Empress burned out of control for 14 days after which it sank. The 3.5 million barrels of crude oil in the Atlantic Empress largely burned except for a small residual slick which was not subsequently tracked and did not hit shore. The Haven burned near Italy and the heavy oil burnt near the wreck formed a bituminous mass that sank within hours after the burn (**7**).

X4. REVIEWS

X4.1 Cabioch (**8 and 9**) prepared a survey of burning in ships. The study reviews accidental burns as well. The author concludes that burning in ships would require a low flash point oil (<20 to 30°C), sufficient ventilation to ignite, at least 10 % of the surface area to be ignited and provision for lateral vents, that the ship's construction be known so that experts can judge the fire resistance of the hull and frame, and that ignition could be carried out using explosives or special devices.

X5. DELIBERATE FIRES IN SHIPS

X5.1 The New Carissa, a wood chip carrier, was ignited to burn bunker oils which, if released, could have caused serious damage to the Oregon coast (**10 and 11**). Explosives were used to drive the oil into a hold area and the oil was ignited subsequently. Approximately 700 tons of oil burned in about 33 hours. Some oil was left in the hull and some oil was released.

X5.2 Reiter and Kemerer (**12**) reviewed the use of deliberate burning on four cases of stranded fishing vessels off Alaska. In every case the burning was successful. The burning was conducted after careful planning and demolition to result in sufficient openings to allow for more complete combustion. In all cases except where noted, the fuel was a heavy fuel oil and burning lasted several hours.

X5.3 The incidents are:

X5.3.1 *M/V Ryuyo Maru #2, off St. Paul Island, Alaska, 1979:* Explosives were used to cut open the hull.

X5.3.2 *M/V Lee Wang Zin, Dixon Entrance, Alaska, 1979:* The vessel was sunk deliberately after the burn.

X5.3.3 *F/V Dae Rim, Bering Sea, 1981:* Explosives were used to cut open the hull to allow for burning. The product burned was diesel fuel.

X5.3.4 *M/V Aoyagi Maru, Akun Island, Alaska, 1988:* Charges were used to drive the bunkers into the hold and diesel fuel which had been offloaded earlier was then pumped on top of the bunker and ignited. The burn was successful and lasted two weeks.

X5.3.5 *The Edgar Jordain:*

A general cargo carrier, it ran aground on Hall Beach in Canada's Arctic in 1980 and after oil was discovered leaking in 1981, the cargo of 60 to 70 tons of diesel fuel, possibly mixed with a small amount of other fuels and lube oils, was ignited (**13**). This burned completely in several hours.

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