Standard Guide for
In-situ Burning of Oil Spills on Water: Ice Conditions[1]

1. Scope

1.1 This guide addresses in-situ burning as a response tool for oil spills occurring on waters with ice present.

1.2 There are several methods of control or cleanup of spilled oil. In-situ burning, mechanical recovery, dispersant application or natural recovery are the usual options available.

1.3 The purpose of this guide is to provide the user with general information on in-situ burning in ice conditions as a means of controlling and removing spilled oil. It is intended as a reference to plan an in-situ burn of spilled oil.

1.4 This guide outlines procedures and describes some equipment that can be used to accomplish an in-situ burn in ice conditions. The guide includes a description of typical ice situations where in-situ burning of oil has been found to be effective. Other standards address the general guidelines for the use of in-situ burning (Guide F1788), the use of ignition devices (Guide F1990), the use of fire-resistant boom (Guide F2152), the application of in-situ burning in ships (Guide F2533), and the use of in-situ burning in marshes (Guide F2823).

1.5 In making in-situ burn decisions, appropriate government authorities should be consulted as required by law.

1.6 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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 requirements prior to use.* Specific precautionary information is given in Section 8. Guide F1788 addresses operational considerations.

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
F2152 Guide for In-Situ Burning of Spilled Oil: Fire-Resistant Boom
F2533 Guide for In-Situ Burning of Oil in Ships or Other Vessels
F2823 Guide for In-Situ Burning of Oil Spills in Marshes

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *brash ice*—floating ice fragments less than 2 m across.

3.1.2 *close pack ice*—pack ice with concentration of 7/10 to 8/10 (fraction of a whole).

3.1.3 *fast ice*—ice attached to the shoreline.

3.1.4 *fire-resistant boom (FR)*—boom designed to contain burning oil (Guide F2152).

3.1.5 *fracture or lead*—any break or rupture through very close pack ice, compact pack ice, fast ice, or a single floe.

3.1.6 *frazil or grease ice*—ice crystals forming on surface of water, ice, or melt pools.

3.1.7 *fresh oil*—oil recently spilled, remaining un-weathered and un-emulsified.

3.1.8 *ice coverage*—a combination of ice pans, ice chunks, bergy bits covering 10 % to near 100 % coverage of water surface, more accurately described using other terms in this section such as *close pack ice*, *open water*, and so forth.

3.1.9 *in-situ-burning*—burning of oil directly on the water surface.

3.1.10 *melt pools*—accumulations of melt water on the surface of ice during thawing.

3.1.11 *open drift ice*—ice concentration of 4/10 to 6/10.

3.1.12 *open water*—less than 1/10 ice concentration.

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[1] This guide is under the jurisdiction of ASTM Committee F20 on Hazardous Substances and Oil Spill Responseand is the direct responsibility of Subcommittee F20.15 on In-Situ Burning.

Current edition approved Nov. 1, 2014. Published December 2014. Originally approved in 2002. Last previous edition approved in 2008 as F2230 – 08. DOI: 10.1520/F2230-14.

[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.

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

3.1.14 *rotten ice*—sea ice that has become honeycombed and is disintegrating.

3.1.15 *very close pack ice*—pack ice with concentration of 9/10 to 10/10.

3.1.16 *very open drift ice*—ice concentration of 1/10 to 3/10.

4. Significance and Use

4.1 This guide is meant to aid local and regional spill response teams during spill response planning and spill events.

5. General Considerations for Making In-situ Burn Decisions

5.1 For marine spills of oil in ice conditions, in-situ burning should be given equal consideration with other spill countermeasures and may be the best available technology for ice conditions. In some cases, in-situ burning may be the only practical option.

5.2 The decision of whether or not to use in-situ burning in a given spill situation is always one involving trade-offs, that is, smoke plume and burn residue compared to oil left alone.

5.3 One of the limitations of recovery techniques for floating oil is effective containment of the slick. In-situ burning is subject to this constraint as a minimum thickness of about 2 mm is required for ignition and sustained burning of the slick. Natural containment of spilled oil can occur in some ice conditions. The presence of ice can inhibit the spreading and weathering of the oil slick. At higher ice concentrations, oil will spread more slowly than it would in open water. When ice concentrations are lower, spreading can still be reduced by the effect of wind herding. Oil herded by wind can concentrate against ice floes and can accumulate to thicknesses capable of supporting combustion or by the use of chemical herders.

5.4 In this guide, environments suitable for in-situ burning will be discussed. The matrix in Table 1 is provided to assist users of this guide.

5.5 Burning in an ice environment may be conducted remotely, lessening safety concerns.

6. Marine Environments

6.1 For the purpose of this guide, in-situ burning in ice conditions refers to marine and coastal waters, rivers, and lakes where oil spills may occur in ice-infested waters.

7. Background

7.1 In-situ burning protects the marine environment from the effects of an oil spill by consuming the oil by fire leaving as little as 1 to 10 % oil residue on the surface of the water (Guide F1788). By removing the oil from the water and ice, the impacts on the surface and sub-surface biota are reduced. Unburned oil may ultimately impact shorelines, including critical habitats such as marshes and bird rookeries. Oil floating on the surface has the potential to contact sea birds and marine life. Stranded oil may result in adverse environmental impacts. The amount of oil spilled, the degree of ice cover, and weather conditions are factors that determine the impact of a spill and the burnability of the oil.

7.2 In-situ burning of an oil spill requires an ignition source with the ability to provide multiple ignitions (see Guide F1990). The helicopter sling-mounted drum filled with gelled gasoline or diesel developed for lighting backfires during forest fire fighting is an effective system for igniting oil in ice conditions. Individual hand-held igniters dropped from aircraft or deployed from vessels may be used to ignite oil contained by ice. Since burning is most efficient when the oil is relatively fresh and un-emulsified, sources of ignition should be identified by response planners in their pre-spill contingency planning.

TABLE 1 Burn Strategies for Different Arctic Conditions

Type of Waters	Status of Oil	Strategy
Marine Coastal Waters		
Open water (0/10 to 1/10)	Contained fire-resistant(FR) boom	Burn oil in boom
Very open drift ice (1/10 to 3/10)	Possibly contained by FR boom	Burn oil in boom; use herding agents to concentrate oil
Open drift ice (4/10 to 6/10)	Herded by wind or contained by ice	Burn oil where sufficient thickness; use herding agents to concentrate oil
Close pack ice (7/10 to 8/10)	Contained by ice leads or floes	Burn oil in leads and between floes
Very close pack ice (9/10 to 10/10)	Contained in leads and fractures	Burn oil in leads and fractures
Fast ice	Contained on surface of ice	Burn oil where sufficient thickness
Melt pools	Oil contained on melt pools or on surface through brine channels	Burn oil where sufficient thickness
Rivers		
Open water	Deflect and contain oil in FR boom	Burn oil in boom
Brash, moving ice conditions	Look for areas of oil pooled by wind, current or ice	Burn where sufficient thickness
Solid ice, oil under ice	Slot ice, deflect oil to surface to burn	Burn oil where pooled on surface
Solid ice, oil on top of ice	Dam oil on top of ice to contain and pool	Burn oil where pooled on surface
Lakes		
Open water	Contain in FR boom	Burn oil in boom
Brash ice conditions	Look for areas of oil pooled by wind, current, or ice	Burn oil where sufficient thickness
Solid ice, oil under ice	Drill or slot ice to bring oil to surface	Burn pools of oil on surface
Solid ice, oil on top of ice	Dam oil on top of ice to contain and pool	Burn oil where pooled on surface

7.3 In open waters and in open and very open drift ice, containment by special fire-resistant booms may be required (Guide F2152).

8. Recommendations

8.1 Use of helicopter-mounted ignition systems or individual igniters is a hazardous operation and all applicable safety instructions for their use should be followed. Hazardous materials may have to be handled as part of the ignition equipment. Appropriate MSDS sheets should be available and followed during use of this equipment.

8.2 The in-situ burning of spilled oil can be accomplished under favorable conditions when oil is:

8.2.1 Contained in close pack ice conditions (pack ice of 7/10 coverage or greater).

8.2.2 Contained in drift ice conditions is sufficient thickness to sustain a burn (drift ice of 2/10 to 6/10).

8.2.3 Contained in fire-resistant boom (generally open water up to 1/10 ice coverage).

8.2.4 Trapped along an ice floe or herded by wind and has sufficient thickness to support a burn.

8.2.5 Contained in melt pools on top of ice sheets.

8.2.6 Contained in open fractures or leads in ice.

8.2.7 Flowing under ice in a stream and ice can be slotted to bring oil to surface to burn.

8.2.8 Spilled on surface of ice and has sufficient thickness to support a burn.

8.3 In-situ burning of oil may require certain regulatory approvals.

8.4 Although in-situ burns are efficient, there always will remain some residue and provisions for the recovery of that residue should be included in in-situ burn response planning.

9. Keywords

9.1 arctic oil spills; ISB; ice conditions; in-situ burning; oil spills

APPENDIXES

(Nonmandatory Information)

X1. BACKGROUND INFORMATION ON ARCTIC IN-SITU BURNING

X1.1 Several field experiments have been conducted in the Arctic waters to determine the feasibility of burning oil in ice-infested waters. One experiment involved the release of 30 tons of fresh crude oil. It was observed that the oil weathered more slowly and to a lesser extent in ice than it would have in open water (**1**)[3]. After approximately 10 days, samples of the oil showed that it had lost 20 % of its volume due to evaporation and that it had formed a 20 % water-in-oil mixture. These results indicated that oil spilled in such ice conditions could feasibly be treated using in-situ burning techniques. Burning was in fact evaluated as the best response method available for this particular spill situation (**1**). Another recent study evaluating different response methods for several possible spill scenarios for the Arctic concluded that in-situ burning would likely be the most effective option under certain circumstances (**2**).

X1.2 Other field experiments have been carried out to determine the effect of wind or lack of wind on the flame spreading from one slick area to another slick area, either directly connected to or physically separated from the burn area. Ambient temperatures for these experiments were typical winter range of -20 to +5°C. Wind speeds ranged from 5 to 15 m/s with some occasional calm periods. The small basins of oil (0.5 by 1.5 m) designed to simulate an ice pack were separated from the main burn basin (15 m dia.) by 1.5 to 3.5 m. A 10 mm layer of crude oil, at different degrees of weathering, was placed in these basins. During relatively calm conditions, there was no spreading of flames from the main burn. When the wind was blowing from 2 to 11 m/s there was enough flame tilt (30 to 35 angle from horizontal) to ignite oil with 25 % of the light ends evaporated and a water-in-oil mixture containing 50 % water in the small basins 1.5 to 3.5 m from main burn. Efficiencies of these burns were measured at over 95 % (**1**). Even uncontained crude oil slicks which were burning at release continued to burn at nearly 90 % efficiency until slick thickness thinned to less than 1 mm (**3**).

X1.3 Experiments have been conducted on Alaskan crude oils to determine burnability when fresh, weathered and emulsified with and without emulsion breakers. If the oil is not more than 20 % weathered and 20 % water-in-oil mixture, then expected efficiency of burn will exceed 90 % (**4, 5**). Oil more weathered or more emulsified may still be burned by using emulsion breakers or adding fresh crude to initiate burn.

X1.4 The field burns have shown that high burn efficiencies can be obtained when burning fresh oil and emulsions contained in ice-infested waters. A mixture of fresh oil and a 50 % water-in-oil mixture burned with efficiencies of over 99 %. A 20 % water-in-oil mixture burns with an efficiency of 95 % in a basin with 50 % broken ice coverage (**1, 4**). The wind herding effect tends to confine the slick to a smaller area and therefore burn for a longer period of time (**6, 7**).

X1.5 Flame spreading in ice conditions was observed mainly in a downwind direction, some spreading occurred sideways and upwind between inter-connected pools of oil. Flame spreading from one burning oil pool to another separate oil pool was dependant on the wind direction and speed (**1, 4**).

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

X1.6 Experiments to test burning of oil in ice leads were conducted to determine the effect of wind herding, oil weathering, and lead geometry on burning efficiencies. Burn efficiencies of up to 90 % were measured. Weathering of oil up to 20 % did not significantly affect the burns (**8**).

X1.7 Igniting spilled oil in ice conditions can be accomplished by a variety of ignition systems. They include hand-thrown igniters and helicopter sling-loaded drum igniters containing gelled gasoline (Guide F1990). The rate at which individual ignition points can be achieved is quite important recognizing the limited time that might be available for completing a large scale in-situ burn operation (**7**). Gelled gasoline, ignited and released from a helicopter-slung drum appears to be an effective means of producing numerous oil ignition sources quickly, safely and at a very small cost per ignition point (**9**). If an oil becomes emulsified before an in-situ burn begins, then a special emulsion breaking mixture delivered in a helicopter-mounted ignition system is able to ignite layers of water-in-oil mixtures (up to 50 % water in oil) (**9**).

X1.8 Quantitative analytical data (from the Newfoundland Offshore Burn Experiment-NOBE and many test burns in tanks) discusses emissions likely to be encountered in a significant offshore in-situ burn (**10**, **11**).

X1.9 In-situ burning has been proven as a tool for oil spill response in Arctic waters. Oil spilled under growing sea ice will become encapsulated within the ice. During the following melt season, the oil will migrate to the surface of the ice through brine channels and appear on the ice surface in melt pools. The rate of migration depends on the degree of brine drainage in the ice, the ice pool thickness, and the oil viscosity. Wind herds the surfaced oil against the edges of individual melt pools, thickening it to burnable thicknesses. Experimental spills in landfast ice in the Canadian Beaufort indicate that most of the oil will appear on the ice surface through this migration process before the ice melts down to the oil layer and well in advance of breakup, and that in-situ burning would be an effective countermeasure (**12**, **13**).

X1.10 Ice slotting: Oil under ice can be recovered using slots cut through the ice (**14**, **15**). Oil can then be burned directly in these slots. Calculation, laboratory tests, and field trials have shown that slots should be at least twice as wide as the thickness of the ice and that the angle depends on the velocity of the river or flow under the ice. An angle of 30° to the current was found to be useful for velocities of 1 to 4 knots. Recovery tests showed that over 90 % of oil released upstream could be recovered in the slots.

X1.11 Chemical herding agents have been tested at lab-, mid- and full-scale and have been shown to concentrate and contain oil for in-situ burning in open and very open drift ice (**16**). Field tests in pack ice in the Barents Sea were done in 2008. One experiment involved the release of 630 L of fresh crude in a large lead. The free-drifting oil was allowed to spread for 15 minutes until it was too thin to ignite (0.4 mm), and then herder was applied around the slick periphery. The slick contracted and thickened for approximately 10 minutes at which time the upwind end was ignited using a gelled gasoline igniter. A 9- minute long burn ensued that consumed an estimated 90% of the oil (**17**).

X1.12 As part of a multi-year lab and field experiment to examine oil spill behavior in ice and various countermeasures for such spills, tests were performed with fire-resistant boom in a range of drift ice concentrations (**18**). In the test program in 2008, tests were performed without oil, and confirmed the ability of two commercially-available fire booms to contain ice while under tow such that a "contain-and-burn" operation could be performed in light ice conditions. Two booms were tested: each boom was able to contain ice at speeds in excess of the normal containment limits of oil, that is, 0.35 to 0.5 m/s. Tow loads were measured and found to be on the order of double the loads experienced in open water.

In 2009, the booms were tested in two different ice conditions, a field of 3 to 5/10ths ice, and in trace ice conditions. In these tests, each boom was deployed and then maneuvered to capture ice floes to fill the boom's apex. Four m^3 oil was released into the contained ice and then ignited. In each test, a high percentage of the oil was removed through in situ burning, about 98% in the first test and about 89% in the second. The tests demonstrated the ability to use fire-resistant booms in light drift ice to collect oil and ice for in situ burning.

X2. HISTORICAL BURNS AND SPILL STUDIES (4, 15)

X2.1 See Table X2.1.

TABLE X2.1 Historical Burns and Spill Studies

Year	Country Location	Description	Events	Lessons
1958	Canada	Mackenzie River, NWT	First recorded use of in-situ burning, on river using log booms	In-situ burning possible with use of containment
1967	Britain	TORREY CANYON	Cargo tanks difficult to ignite with military devices	There maybe limitations to burning
1969	HOLLAND	Series of experiments	Igniter KONTAX tested, many slicks burned	Burning at sea is possible
1970	Canada	ARROW	Limited success burning in confined pools	Confinement may be necessary for burning
1970	SWEDEN	OTHELLO/KATELYSIA	Oil burned among ice and in pools	Can burn oil contained by ice
1970	Canada	Deception Bay	Oil burned among ice and in pools	Can burn in ice and in pools
1973	Canada	Rimouski—experiment	Several burns of various oils on mud flats	Demonstrated high removal rates possible, >75 %
1975	Canada	Balaena Bay—experiment	Multiple slicks from underice oil ignited	Demonstrated ease of burning oil on ice
1976	U.S.A.	ARGO MERCHANT	Tried to ignite thin slicks at sea	Not able to burn thin slicks on open water
1976	Canada	Yellowknife—experiment	Parameters controlling burning not oil type alone	Parameters controlling burning not oil type alone
1978-82	Canada	Series of experiments	Studied many parameters of burning	Found limitations to burning was thickness
1979	Mid-Atlantic	ATLANTIC EMPRESS/ AEGEAN CAPTAIN	Uncontained oil burned at sea after accident	Uncontained slicks will burn at sea directly after spill
1979	Canada	IMPERIAL ST. CLAIR	Burned oil in ice conditions	Can readily burn fuels amongst ice
1980	Canada	McKinley Bay—experiment	Several tests involving igniters, different thicknesses	Test of igniters, measured burn rates
1981	Canada	McKinley Bay—experiment	Tried to ignite emulsions	Noted difficulty in burning emulsions
1983	Canada	EDGAR JORDAIN	Vessel containing fuels and nearby fuel ignited	Practical effectiveness of burning amongst ice
1983	U.S.A.	Beaufort Sea—experiment	Oil burned in broken ice	Ability to burn in broken ice
1984	Canada	series of experiments	Tested the burning of uncontained slicks	Uncontained burning only possible in few conditions
1984-5	U.S.A.	Beaufort Sea—experiment	Burning with various ice coverages tested	Burning with various ice coverages possible
1984-6	U.S.A.	OHMSETT—experiments	Oil burned among ice but not with high water content	Ice concentration not important, Emulsions don't burn
1985	Canada	Offshore Atlantic—experiment	Oil among ice burned after physical experiment	Ease of burning amongst ice
1985	Canada	Esso—Calgary—experiments	Several slicks in ice leads burned	Ease of burning in leads
1986	Canada	Ottawa—experiments/analysis	Analyzed residue and soot from several burns	Analysis shows PAH's about same in oil and residue
1986	U.S.A.	Seattle and Deadhorse—exper.	Test of the Helitorch and other igniters	First demonstrations of Helitorch as practical
1986-91	U.S.A.	NIST—experiments	Many lab-scale experiments	Science of burning, rates, soot, heat transfer
1986-91	Canada	Ottawa—analysis on above	Analyzed residue and soot from several burns	Found PAH's and others - not major problem
1989	U.S.A.	EXXON VALDEZ	A test burn performed using a fire-proof boom	One burn demonstrated practicality and ease
1991	U.S.A.	First set of Mobile experiments	Several test burns in newly-constructed pan	Several physical findings and first emission results
1992	U.S.A.	Second set of Mobile burns	Several test burns in pan	Several physical findings and emission results
1992	Canada	Several test burns in Calgary	Emissions measured and Ferrocene tested	Showed smokeless burn possible
1993	Canada	Newfoundland Offshore burn	Successful burn on full scale off shore	Hundreds of measurements, practicality demonstrated
1994	U.S.A.	Third set of Mobile burns	Large scale diesel burns to test sampler	Many measurements taken
1994	U.S.A.	North Slope burns	Large scale burn to measure smoke	Trajectory and deposition determined
1994	Norway	Series of Spitzbergen burns	Large scale burns of crude and emulsions	Large area of ignition results in burn of emulsions
1994	Norway	Series of Spitzbergen burns	Try of uncontained burn	Uncontained burn largely burned
1996	Britain	Burn test	First containment burn test in Britain	Demonstrated practicality of technique
1996	U.S.A.	Test burns in Alaska	Igniters and boom tested	Some measurements taken
1997	U.S.A.	Fourth set of Mobile burns	Small scale diesel burns to test booms	Emissions measured and booms tested
1997	U.S.A.	North Slope tank tests	Conducted several tests on waves/burning	Waves not strongly constraining on burning
1998	U.S.A.	Fifth set of Mobile burns	Small scale diesel burns to test booms	Emissions measured and booms tested
2001	U.S.A.	Boom tests in OHMSETT	Small scale propane tests of test booms	Tested some new fire-resistant booms
2002	U.S.A.	Small scale tests in Alaska	Tested burning in frazil and brash ice	Frazil and brash ice reduce burning rate
2002, 2003	Canada	Small scale heavy oil burns	Burned heavy oil and Orimulsion in test pans	Burning rate of heavy oil, ignition methods, emissions
2008	Norway	Use of herders for ISB	Two burns of crude oil using chemical herding agents to concentrate and contain the burn.	Demonstrated effectiveness of herders in ice-affected waters.
2009	Norway	Use of fire booms in ice	Used fire-resistant boom to contain burning oil in 1/10th and 5/10ths concentrations.	Demonstrated effectiveness of fire booms in open and very open drift ice.

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