IN-SITU BURNING

A DECISION-MAKER'S GUIDE TO IN-SITU BURNING

REGULATORY ANALYSIS AND SCIENTIFIC AFFAIIRS
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FOREWORD

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OVERVIEW

- The American Petroleum Institute (API) commissioned the preparation of two booklets to help bridge the gaps in the understanding of *in-situ* burning (ISB) use, effectiveness, and effects.
- This booklet (second of two) focuses on the operational ISB considerations and issues associated with *in-situ* burning both on land and on water.
- This series was developed as a training tool or planning tool for *in-situ* burning. It is NOT an operations manual.
- Crude oil is a complex mixture of thousands of different compounds, composed primarily of carbon, hydrogen, sulfur, nitrogen, and oxygen. Hydrocarbons (composed solely of carbon and hydrogen atoms in various combinations) are the most abundant compounds found in crude oils.
- *In-situ* burning involves controlled burning of oil that has spilled from a vessel or a facility, including pipelines.
- For an *in-situ* burn on water to ignite and sustain, the spilled oil must be approximately $^{1}/_{10}$ of an inch or 2–3 millimeters in thickness—so containment in some form is necessary to limit spreading.
- On water, spilled oil is contained within a boom or naturally, such as in ice, and ignited using an ignition source. On land, the oil may need to be contained by physical means (such as dikes), but the spilled oil will collect in natural depressions or low-lying areas where it can be contained and ignited.
- When conducted properly, *in-situ* burning significantly reduces the amount of spilled oil (on the water or on land surface), thereby, preventing that oil from remaining in the environment or moving and affecting other resources and habitats.
- *In-situ* burning offers a practical method to remove large quantities of oil from the land or water surface very quickly, however there are many limiting factors that should be taken into account before a burn is conducted. Physical limitations such as wind speed, wave height, thickness of the oil, oil type, how weathered the oil is, and how emulsified the oil is can limit the feasibility of ISB. Other factors to consider are human exposure to smoke, monitoring requirements, accessibility to the impacted site, and recovery of burned/unburned product and residue.
- As oil weathers, it loses its more volatile components. Emulsification may also occur when water mixes with the oil. Either of these processes make it more difficult to ignite the oil as well as sustain the burn. Optimal oil conditions for burning are less than 30% loss by evaporation and less than 25% water content.

- Equipment needed to conduct *in-situ* burning may consist of:
  - Ignition systems – Helitorch component system, gelled fuel, hand held igniter
  - Fire Booms – fabric booms, metal booms, air bubble and water spray systems, and other boom concepts
  - Firefighting/control equipment
- A burn plan will be required. This plan should address human health and safety issues, burn methods, monitoring plans, termination conditions, and post-burn cleanup and restoration. Attempts should be made to remove all remaining burn residue from the environment.
- Monitoring an *in-situ* burn is essential for success and learning more about its effectiveness and effects. Monitoring can include air quality measures as well as maintaining a constant watch on the fire and smoke plume, condition of the boom, and the speed and positions of the towing vessels, if in open water.
- In the United States, the Special Monitoring of Applied Response Technologies (SMART) was developed to provide monitoring guidance for the collection and reporting of real-time information on *in-situ* burning and dispersant use. SMART allows responders to effectively determine potential human health exposures during a burn so that impacts to the public are minimized or eliminated. SMART allows decision-makers to determine when to stop a burn to ensure limited population impacts. SMART is not intended to determine worker health and safety exposure limits.
- In the United States, before an *in-situ* burn can take place (on land or on water), approval must be received from the appropriate state and federal agencies. The approval process varies from state to state or region to region. In some areas of the United States, regional planning efforts have developed pre-approval zones for *in-situ* burning.
- Human health concerns (for both responders and the public) are addressed in monitoring plans. Responders are equipped with protective clothing and masks, as needed. The primary concern for public safety is that of air quality.
- The smoke from a burn contains particles that have been found to be harmful to humans. The smoke plume reaching receptor populations should not exceed the average federal and/or state air quality standards in public areas; otherwise the burn should not be allowed or should be terminated.
- Also included in the booklet are case studies from various locations with different environments, oil types, and situations. Lessons learned have been developed from these responses, which highlight advantages and disadvantages of *in-situ* burning.

Section I. Introduction

You are in the midst of a large oil spill and it's your first month on the job. Approximately 20,000 gallons of a medium-weight crude oil has been discharged into the environment. Earlier you were asked by the *Unified Command* (UC) to identify options to remove this oil that will also minimize the potential impacts to the environment (see boxes on pages 2 and 3). Based on the circumstances, you recommended that burning the oil in place, *in-situ* burning (ISB), would provide the greatest value in terms of removing the threat of liquid oil to resources at risk in and on the ground and water.


An *In-situ* Burn.

Now, the On-scene Coordinator (OSC) needs additional information. You have been asked to provide more information on *in-situ* burning including the operational issues and concerns associated with conducting an ISB, worker and public health issues, and monitoring. Your research will help the OSC verify the appropriateness of this removal method for the incident-specific spill conditions and determine if the requirements for an *in-situ* burn are achievable within the recommended window of opportunity.

As always, the OSC wants the information as soon as possible. You have had basic oil spill response training, and you have heard of ISB, but this is the first time you have been involved in an ISB response. During your training, you remember that there were several guidance documents that have been developed to assist responders in understanding the concept of ISB.

Unified Command (UC) is responsible for all aspects of the response, including developing incident objectives and managing all incident operations (*refer to information box on Page 3 for more information*).

Actual UC makeup for a specific incident will be determined on a case-by-case basis taking into account:

1. specifics of the incident;
2. determinations outlined in existing response plans; or
3. decisions reached during the initial meeting of the UC.

The makeup of the UC may change as an incident progresses, in order to account for changes in the situation. The UC is a team effort, but to be effective, the number of personnel should be kept as small as possible.

Purpose of This Booklet

This scenario is fictitious but the circumstances are possible. ISB is a response option that has been used less frequently than countermeasures like booms and skimmers or contaminated soil removal. Consequently, familiarity with the pros and cons of this option is limited. There are ISB "experts" in the United States and internationally, but the intentional practice of this response tool remains relatively limited for both on water and on land situations.

This booklet is the second in series that was developed as a reference document for oil spill response decision-makers. It provides the reader with a comprehensive, concise, yet clear summary of the operational requirements and limitations for ISB, and allows decision-makers to better understand the function of *in-situ* burning and the tradeoffs facing decision-makers in using this technology when responding to an oil spill on land or on water.

The first booklet, “The Fate of Burned Oil” (API Publication No. 4735), was prepared to provide an accurate summary of the fate and effects of burned oil on water and on land, as well as in the air.

Throughout both booklets, the first time a new technical term is used, it will appear in an ALL CAPS format; this signifies that a more detailed explanation or definition is present in the right or left margin near where the word(s) is first used within the main text.

For More Information…

The American Petroleum Institute commissioned the development of the booklet, “Fate of Spilled Oil in Marine Waters: Where Does it Go? What Does It Do? How Do Dispersants Affect it? An Information Booklet for Decision-makers” (API Publ. 4691).

This booklet provides a more detailed summary on oil chemistry and is recommended reading. This booklet is available from API Publications at www.api.org.

A Team Effort…
The Incident Command System, Unified Command, Incident Commanders, On-scene Coordinators, and Responsible Parties

During a response to an oil spill, in many cases there are several federal agencies as well as state and local agencies from the affected area that become involved with the response efforts. The **Incident Command System (ICS)** is a response tool that has been almost universally adopted by state and federal agencies as the method of rapidly organizing a coordinated response to an incident, such as an oil spill. If all agencies involved in the incident are using the same categories to address critical needs to manage their agency, the cooperative effort of all the agencies will increase dramatically.

The **Unified Command** structure is a necessary tool within the ICS for managing multi-jurisdictional responses to oil spills or hazardous substance releases. When planned for and practiced, ICS/UC is viewed as the most effective response management system to address discharges or releases. The ICS/UC is an integrated and flexible structure that emphasizes cooperation and coordination in local, state, and federal responses to complex multi-jurisdictional, multi-agency incidents.

Within the ICS/UC, there is a requirement for a single individual, or **Incident Commander (IC)** to be the final decision-maker for the efforts of the response. The UC is a structure that brings together the "Incident Commanders" of all major organizations involved (federal, state, local, and **Responsible Party** groups) in the incident in order to coordinate an effective response while at the same time carrying out their own jurisdictional responsibilities. These "Incident Commanders" are typically referred to as **On-scene Coordinators (OSC)**—those individuals who have the pre-designated legal authority to make decisions for their agency during an incident, including the access and disbursement of funds to address their agency's response needs. There may be Federal On-scene Coordinators (FOSCs) from EPA and the U.S. Coast Guard; the affected State(s)' On-scene Coordinators (SOSCs); and Local OSCs representing their local jurisdictions. The UC links the organizations responding to the incident and provides a forum for these entities to make consensus decisions. Under the UC, the various jurisdictions and/or agencies and non-government responders may blend together throughout the operation to create an integrated response team.

The UC is responsible for overall management of the incident. The UC directs incident activities, including development and implementation of overall objectives and strategies, and approves ordering and releasing of resources. Members of the UC work together to develop a common set of incident objectives and strategies, share information, maximize the use of available resources, and enhance the efficiency of the individual response organizations.

Unified Command speaks to the issue that all of the major players in an incident need to get together to share information, resources, and responsibility for the smooth delivery of effective service. But, as in all events, there can only be one boss, one "shot caller," directing the focus of the group, and setting the group's goals. This whole system of "who's in command" and Unified Command only works if all agencies are aware of each other's primary needs.

For more information on ICS and the Unified Command, access the National Response Team's "Incident Command System/Unified Command Technical Assistance Document," available from:
http://nrt.org/production/nrt/home.nsf/resources/Publications1/$File/ICS_UC_Technical_Assistance_Document.pdf.

Section II. Oil Chemistry Review

Hydrocarbons are defined as chemical compounds composed solely of carbon and hydrogen that come in various lengths and structures.

Trace Metals in oil consist primarily of Nickel, Iron, Vanadium, Copper, and Arsenic.

Asphaltenes and **Waxes** are components in the oil that are considered relatively inert and resistant to most weathering processes.

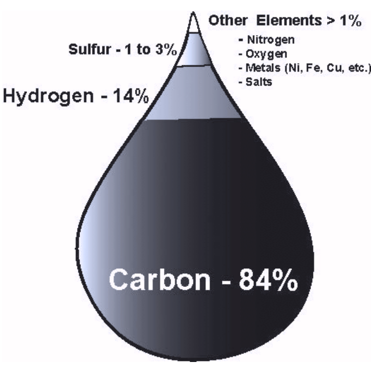


Figure 1. Crude Oil Composition

What is Oil?

Oil is not one "thing;" it is a complex and highly variable mixture of compounds. Even oil extracted from the same well may change in component mixtures over time (Lewis and Aurand, 1997). Crude oil, the unprocessed oil that is recovered from the ground, is composed primarily of ***HYDROCARBONS***, and to a smaller extent compounds containing ***TRACE METALS*** (Figure 1). Hydrocarbons (including ***ASPHALTENES*** and ***WAXES***) are the most abundant compounds in crude oils (NRC, 2003). In general, there are three groups of hydrocarbons in every oil:

- Light-weight components (low molecular weight)
  - contain 1 – 10 carbon atoms in each molecule (C1 to C10);
  - are simple in molecular structure;
  - evaporate and dissolve rapidly (hours) and leave little or no residue ;
  - many of these components (e.g., benzene) are thought to be readily absorbed by animals through the skin or through inhalation; and
  - are potentially flammable and readily inhaled by people, and so are of concern for human health and safety.
- Medium-weight components (medium molecular weight)
  - are composed of 11 – 22 carbon atoms (C11 – C22);
  - are more complex molecules than light-weight;
  - evaporate or dissolve more slowly, over several days, with some residue remaining;
  - are sometimes regarded as a greater concern than the light-weight components since they persist in the environment longer and therefore present a longer term risk of exposure (NRC, 2003); and
  - are not as bioavailable as lower-weight components, so are less likely to affect animals.
- Heavy-weight components (high molecular weight)
  - made up of 23 or more carbon atoms (≥ C23);
  - undergo little to no evaporation or dissolution; and

- can cause chronic (long-term) effects via smothering or coating, or as residue in the water column and sediments (NRC, or 2003).

Crude oils are composed of various combinations of the three hydrocarbon categories. When comparing crude oils, the relative concentration of the larger molecular compounds within the oil affects ***PERSISTENCE;*** oils with greater concentrations of medium- and heavy-weight components will typically result in increased persistence. Oils composed primarily of the lightweight components are usually considered ***NON-PERSISTENT.***

REFINED PRODUCTS are typically composed of a narrow range of processed components, usually containing the lighter-weight components (e.g., gasoline, condensates, and diesel-like products). Low ***API GRAVITY*** oil products are primarily composed of heavy-weight components sometimes mixed with a blending agent (No. 2 fuel oil is a common blending agent) in the development of these heavy refined oils. (See Figure 2 on next page for more information on the oil refinery process.) There are also several naturally occurring crude oils that are considered low API gravity oil products (NRC, 1999).

Behavior and Weathering Effects

When oil is spilled at sea or on land, it is subject to different transport and weathering processes (more information on weathering of oil is available from Scholz et al., 1999; NRC, 2003). Of the eight major weathering and behavior processes, the following can directly influence slick ignition and burning:

Advection: Advection or drifting only occurs for spills on water. It is the process of surface slicks being transported away from the site of a spill by water currents. Advection is usually a combination of residual current movement and wind-induced surface movements. Other causes of movement may occur from tidal currents, river outflows, and longshore currents. The advection process influences the location of slicks and thus determines whether the oil can be burned from a safe distance from the spill source or from land where people, property or other resources can be at risk. Advection can move the oil away from land, sensitive resources, or population centers; it can also move the oil toward these resources of concern.

Persistence is a means of defining how crude and refined oil products may remain in the environment. Persistent oils may not be completely removed from an affected environment as a result of weathering processes or clean-up operations.

An oil that is considered **Non-persistent** is a refined product that will be completely removed from affected environments through natural weathering processes. They are largely composed of light-weight components. Examples include gasoline, No. 2 fuel oil and diesel.

Refined Products include petrochemical products developed in various refinery processes, like gasoline, diesel, bunker fuel oils, etc. For more information on the refinery process, see the next page.

API Gravity (°API) is a scale for measuring fluid specific gravities based on an inverse relationship with specific gravity (SG). This scale was primarily developed to expand the scale for specific gravity so that larger values are used. An oil with a low specific gravity (e.g., gasoline; SG = 0.73) will have a high API gravity (API = 62).

API gravity = (141.5/SG at 60ºF) – 131.5

More on Refining Oils…

Crude oils contain hundreds of different types of hydrocarbons and other components mixed together. Crude oil composition can vary widely from well to well in the same region. There are often noticeable differences between crude oils that are recovered at different times from within the same well.

In the refining process, oils are separated into various hydrocarbon components, also known as fractions or cuts, based on the number of carbon atoms in each molecule. By heating the crude oil and letting it vaporize, the distillation process (also known as fractional distillation) allows the collection and retrieval of the different hydrocarbon molecules based on their vaporization temperatures.

Newer distillation techniques (catalytic cracking) allow a refinery to process the crude oils into the various fractions, but it also allows the breaking of longer chains into shorter ones. This technique allows a refinery to produce a specific product (e.g., gasoline versus diesel fuel), based on demand for the product. The oil remaining after distillation is called the residual or residuum.

Refineries must treat the fractions that they produce to remove impurities. Then, using the various fractions collected, they often combine the processed and unprocessed crude oils to create the desired product. For example, the combination of residual oils and diesel fuel are often used to create Number 6 fuel oil for power plants or bunker fuels.

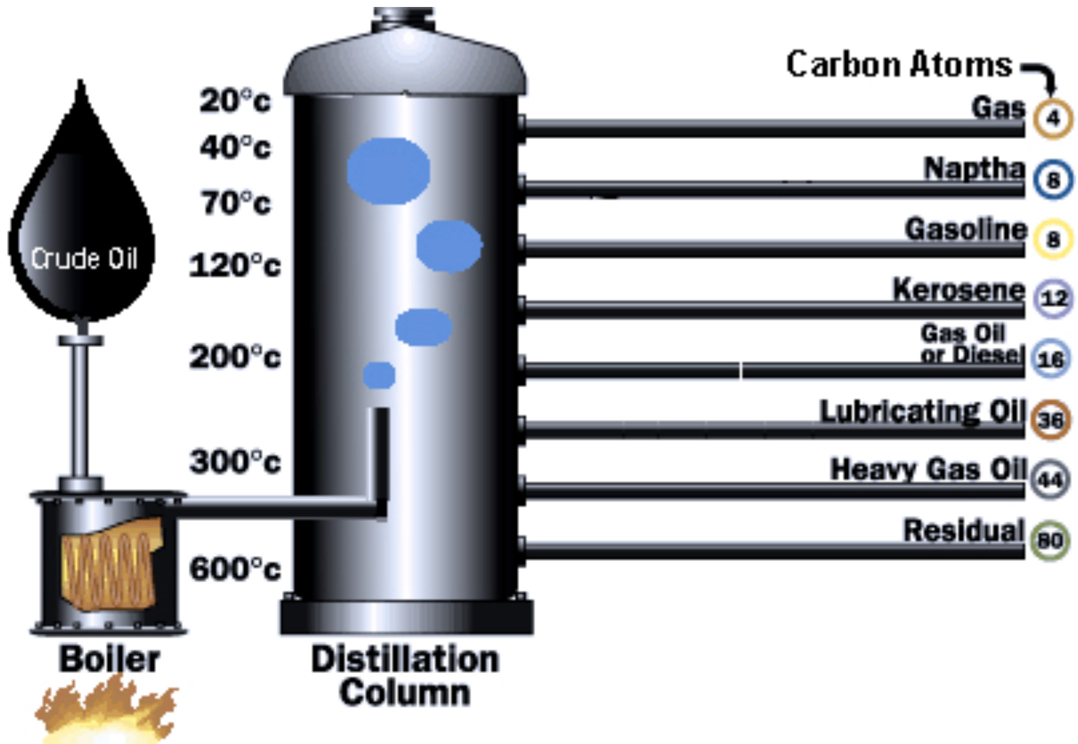


Figure 2. Generic Fractional Distillation in the Crude Oil Refining Process.

Spreading: Spreading is a key process for *in-situ* burning on land and on water because the thickness of an oil slick is determined by the spreading rate of the oil spill. The ignitability and burnability of an oil spill is strongly dependent on the thickness of the slick. Another element influencing the spreading factor on water is the SPECIFIC GRAVITY of the spilled oil. The oil's specific gravity will determine where in the water column the oil will float. If the oil does not float, it is not a candidate for *in-situ* burning.

Specific Gravity is defined as the ratio of the mass of a given material (e.g., oil) to the mass of freshwater, for the same volume and at the same temperature. Most crude oils and refined products have specific gravity values (SG) between 0.78 and 1.00. If the SG of the oil is less than the SG for the receiving water (fresh-water = 1.0 at 4ºC; seawater = 1.03 at 4ºC), it will float on the water surface.

Evaporation: Evaporation is one of the most important processes that affect the properties and behavior of any spilled oil. Highly evaporated oils are difficult to ignite and burn because the remaining heavier weight components don't readily sustain burning. Therefore, it is important to understand evaporation rates for various oil types and how evaporation affects the properties of the oil remaining on the surface.

Emulsification: When crude oils and heavy refined oils are spilled at sea, they often form water-in-oil emulsions, which occur in the presence of mixing energy usually from wave action. During emulsification, water is incorporated into the oil in the form of microscopic droplets. When water content of a slick reaches 50% – 85% (depending on oil type), ignition and burning become very difficult, if not impossible, without the use of special additives.

Natural Dispersion and Dissolution: Dispersion and dissolution are physical processes that move the oil and the more soluble lower molecular weight hydrocarbons from the slick into the water-column. For *in-situ* burning, dispersion and dissolution effects will remove oil from the slick into the water column that could otherwise be burned. Under moderate to high turbulence or wave action, "temporary dispersion" may occur. This is where relatively large oil droplets may break from the slick causing them to be temporarily submerged and when they resurface, they can be outside the burn area and may remain unburned in the environment.

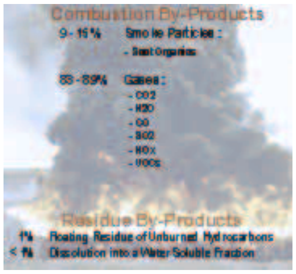


Figure 3. Oil Combustion By-products.

Particulate Matter (PM-10) is the general term used for a mixture of solid and liquid droplets found in the air. PM-10 refers to small, coarse (10 microns in diameter or smaller) particulate matter that is potentially harmful if inhaled because it may become lodged in the lungs.

How Does Burning Change the Oil?

Burning the oil *in-situ* allows for the rapid removal of liquid oil, that has been collected and contained, from the ground and water surface. An ISB converts the liquid oil into its primary gaseous combustion products—water and carbon dioxide, plus a smaller percentage of other unburned or residual byproducts, including soot and gases (NRT, 1992). ISB does not completely remove spilled oil from the environment; the burned oil is primarily converted to airborne residues (gases and large quantities of black smoke or soot) and burn residue (incomplete combustion by-products) (see Figure 3). The airborne residues have the potential to negatively impact natural resources by introducing toxic components through inhalation or direct contact with the various combustion by-products. For more information, refer to Section VI within this volume.

During an ISB, the effect of the combustion plume on downwind human populations and natural resources is a significant concern. One of the key issues associated with ISB effects is the presence of ***PARTICULATE MATTER,*** and particularly the small particles less than 10 microns in diameter that are referred to as "PM-10." The particulate matter in the smoke is composed primarily of elemental carbon. Particles smaller than 10 microns are easily inhaled and drawn deeply into the lungs where they can lodge and cause damage.

Carbon dioxide is the primary gaseous by-product from an ISB. Additional gaseous by-products include carbon monoxide, nitrogen oxides, sulfur oxides, and volatile organic compounds. Human exposures (acute and chronic) to each of these gases (CO, NO_x, SO_2, and VOCs) are regulated by the USEPA's National Ambient Air Quality Standards (NAAQS) and the Occupational Safety and Health Administration (OSHA). OSHA requires that the levels of exposure must be monitored when humans can be exposed to these chemicals via inhalation or direct dermal contact (like during an *in-situ* burn).

Section III. *In-situ* Burning

What is It?

In-situ means “in place.” *In-situ* burning refers to the controlled burning of oil spilled from a vessel, facility, pipeline, or tank truck close to where the spill occurred (ASTM, 2003a). For spills on open water, responders usually have to collect and contain the oil using fire-resistant booms, because the oil has to be a minimum thickness to be ignited and sustain burning. In ice-infested waters, the ice can act as a natural boom, keeping the oil thick enough to burn. *In-situ* burning can also refer to burning of oil inside a vessel before it discharges.

In-situ burning of spills on land occurs more often than on water because the oil doesn’t emulsify, submerge, or spread into thin sheens as quickly, and the oil is usually more accessible. Most of the time, *in-situ* burning on land is conducted shortly after a spill is discovered, when the oil is still thick.

Figure 4. An Example of a Hand-held Igniter. [Image from FOSS Environmental at www.fossenv.com.]

Ignition Sources

A fire can be started with a range of ignition sources, from a simple match to more sophisticated equipment (see Figure 4 and 5). The ignition source is used to provide enough heat for a long enough period so that some of the oil vaporizes and the vapors ignite. Heavy oils require longer heating time and a hotter flame to ignite, compared to lighter oils. A key goal during an on-water burn is to ignite as much of the oil surface as possible, so that the oil is heated enough to form vapors and sustain the burn.

Gelled Gasoline is a gasoline/diesel mixture formed by adding a chemical thickener to gasoline. Thickeners include aluminum soaps, wax, tallow, etc.

Specialized ignition sources include the “Helitorch,” an incendiary device that hangs from a helicopter and drops a burning napalm-like substance **(GELLED GASOLINE*)*** onto the area to be burned (Figure 5). The Helitorch requires a highly trained flight crew to operate the equipment effectively. The gelled gasoline is loaded into a 55-gallon tank on the Helitorch. The fuel is pumped through a nozzle and ignited with propane jets. The falling stream of burning fuel separates into individual globules that burn for 4 – 6 minutes, igniting the oil or other combustible material. Its success rate is high, and it has ignited crude oil in winds up to 16 knots (30 km/hr). Helitorches are commercially available, being first developed for fire-fighting and forestry management. They are safe because they allow ignition from a distance, thus keeping people removed from the open fire.

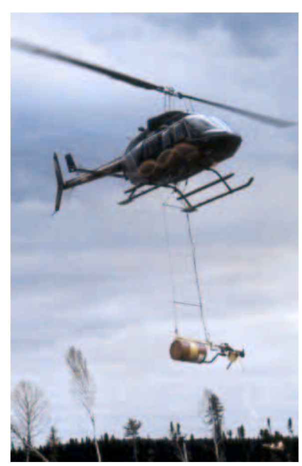


Figure 5. A Helitorch.

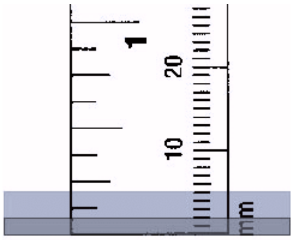


Figure 6. Typical Minimum Oil Slick Thickness Range (2–5 mm) Required for Ignition.

Spill responders have also developed simple ignition devices that can be quickly put together following a spill on water using readily available materials. Examples include:

- Diesel-soaked rags or a roll of toilet paper,
- Oil-soaked sorbent material,
- A sandwich "baggie" filled with gelled gasoline that is allowed to drift into oil contained in a fire boom or by ice, or
- Marker flares (e.g., road flares).

Burns of oil spills on land or wetlands have been ignited using flame or drip torches, flares and flare guns, blowtorches, and oil-soaked rags or sorbents. A common accelerant used in drip torches at prescribed burns is a 70:30 mix of diesel and gasoline.

How is *In-situ* Burning Conducted?

On Water

In-situ burning is conducted differently for spills on water versus land. On water, spilled oil rapidly (within hours) spreads into very thin slicks that are too thin to burn. Therefore, unless the response is very rapid, the oil has to be collected and concentrated into thicker slicks. The oil may also emulsify and evaporation may remove most of the burnable components, making burning of collected oil difficult or unachievable beyond the first 12 – 24 hours after it is spilled. Thus, on water *in-situ* burning is primarily considered an option for incidents with a continuous release source (e.g., a well blow-out) or when oil is trapped in ice.

Oil Thickness Requirements

Fresh crude oil has to be at least 1 millimeter (mm) thick before it can be ignited on water, whereas oil that has undergone extensive weathering may need to be at least 2 mm – 5 mm (see Figure 6). Heavy fuel oils need to be contained to maintain at least a 10 mm or nearly one-half an inch slick thickness. Once ignited, a burn will continue until the oil slick is less than about 2 mm – 3 mm, or about $^{1}/_{10}$ of an inch thick.

The reason that slick thickness is so important for on-water burning is that very thin slicks are rapidly cooled by loss of heat to the underlying water. To burn, oil must be heated enough to vaporize some of the oil's components. It is actually the oil vapors forming above the slick that burn, not the liquid oil. A thicker oil slick acts as an insulating layer, whereas, a thin oil slick cools to the point that vapors are not formed and the fire goes out. Experiments have been conducted to measure the thickness at which the fire goes out, so these "rules of thumb" are generally well accepted.

Equipment Requirements

There are three types of fire-resistant booms (examples to right):

a. Those constructed of steel;

b. Those constructed from fire-resistant fabrics; and

c. Those employing active water cooling systems.

For spills in ice-covered waters, the oil often accumulates in the spaces between the ice and can be readily burned without using boom. It may be necessary to cut holes in the ice where the oil is trapped under the ice away from natural breaks.

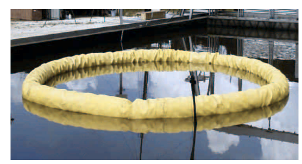
Operational Guidelines

For spills on open water, *in-situ* burning is ideally accomplished in the following steps (Buist, 1998):

1. Two vessels collect a patch of oil in fire-resistant boom that is towed until the oil fills about one-third of the area inside the boom (see Figure 7).
2. The boom is towed a safe distance from other patches of oil.
3. The oil inside the boom is ignited (see section above on ignition sources). The boom is slowly towed into the wind, to keep the oil toward the back of the boom and so that the smoke will go behind it.
4. The oil burns until the fire goes out. If there is a problem, it is possible to let one end of the boom go, allowing the oil to spread into a thin slick and the fire goes out quickly.
5. Any floating oil residue is collected (see Figure 8), and the boom is inspected for damage.
6. The boom is towed to pick up the next batch of oil.

If the oil is continually leaking from a source, such as a well blowout, the fire-resistant boom can be positioned to capture the oil a safe distance from the source. The oil is burned as it accumulates inside the boom.

a. Steel Construction Boom



b. Fire-resistant Fabric Boom

c. Water Cooling System Boom

Figure 7. Oil collection on water.

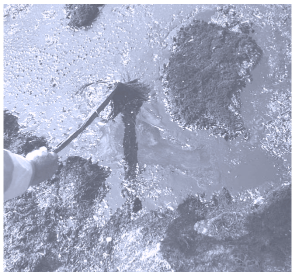


Figure 8. Burn residue recovery on water and on land.

Health and Safety

For small crude oil spills (less than 30 feet [9.1 meters] in diameter) on water, the height of the flames is generally twice the width of the burning oil. For large spills (greater than 300 ft [100 m] in diameter), the height of the flames is about the same as the width of the burning oil (Buist et al., 1994). The diameter of the fire is also important in determining the safe distance for responders.

A safety zone(s) should be defined for ISB personnel as well as areas that are acceptable for burning operations. A safety zone(s) also needs to identify areas where ignition and sustained burning operations will not be permitted. Safety zones must be established with consideration for the key hazards for personnel involved in an ISB response, including risk from flashbacks, secondary or unintentional fires, exposure to the heat and smoke emissions from the fire.

This means that the positioning of the response personnel relative to the active burn site should be taken into consideration from a health and safety standpoint (see Section VI). A responder at an active burn site will have greater potential for exposure to the airborne burn residues the closer he/she is to the burn site, depending on existing weather conditions (wind direction, speed, etc.). Buist, et al. (1994) calculated the safe distance for oil fires to be:

Exposure Time (min.)	Safe Approach for Personnel (fire diameters)
Infinite	4
30 minutes	3
5 minutes	2

The use of these health and safety guidelines will help prevent unwanted exposure and injury to response personnel. The risk of exposure to smoke emissions should be minimal or non-existent by ensuring that all vessels/personnel are positioned upwind or crosswind to the target slicks prior to ignition and during the burn.

On Land

In-situ burning of spills on land can be done in a wider variety of ways, depending on the site conditions.

Oil Thickness Requirements

For spills in wetlands where there is a layer of water underneath the oil slick, the minimum thickness rules discussed above usually apply. Often the oil is naturally contained by being trapped in the vegetation or concentrated in open water areas. For spills on land that do not have any natural containment, temporary dikes can be constructed to contain and isolate the oil for burning.

For spills on snow, two burning approaches can be used. Oiled snow can be plowed into piles and burned right on the ground or on the ice. Alternately, oiled snow can be removed with front-end loaders, loaded into dump trucks, and hauled to a burn pit (ACS, 1999).

Figure 9. Example of Firebreaks.

Equipment Requirements

Oil boom is not typically used during burns on land, unless containing the spilled oil to the proper thickness is required and boom is the appropriate equipment for the situation.

Depending on the site, it is often necessary to establish firebreaks so that the fire does not spread outside of the oiled area. A firebreak is a barrier to the spread of the fire by providing a break in the burnable fuel that feeds the fire (see Figure 9). Once the fire reaches the break, it goes out because there is not enough fuel to sustain the fire (although high wind conditions have been known to cause a fire to "jump" the break). For oil spills on land, a firebreak can be created by:

- Disking the land surface at the perimeter of the planned burn, so that there is no flammable vegetation present, just bare soil.
- Digging a trench and creating a dike with the excavated materials.
- Wetting down sparse vegetation with water, using a fire hose or other form of application.
- In isolated marshes, "laying down" the vegetation by repeatedly running over it with an air boat.
- Conducting a small, controlled burn that removes all the flammable materials around the main burn area.

Operational Guidelines

Ignition of the slick is addressed earlier in this section. After the initial burn, the area would be inspected to find and re-ignite any unburned oil. It may be necessary to remove any burn residue. Once the burn is over, responders would put out hot spots by wetting them down or covering them with dirt.

Health and Safety

As mentioned previously, worker health and safety issues must be considered when conducting a burn (see Section VI for more information). Planning for ISB operations requires that adequate health and safety plans be developed for response personnel.

Why You Use *In-situ* Burning?

The priorities for any oil spill response are to protect health and safety of the public and responders, secure the source and stabilize the situation, and begin containment and removal actions. To address these objectives, decision-makers work to remove the threat of spilled oil and reduce the environmental impacts from the spill. The main advantage of using *in-situ* burning is that large volumes of oil (which are physically contained to the required slick thickness) can be removed rapidly from the surface of the land or water under ideal conditions This transferal of the oil from the water or land surface into the atmosphere also reduces the need for temporary storage for recovered oil. As an example, fresh oil can burn at a rate of 3 mm /min, meaning that a pool of oil 300 ft (91 m) in diameter could theoretically burn at the rate of over 400,000 gallons per hour. However, most oil spill slicks are thin so the fire burns through a patch of oil in minutes.

There are operational constraints that affect the oil removal efficiency of ISB. For open water spills, it takes time to corral a patch of oil to the required thickness in a safe area, burn it, recover the residue, inspect the boom, and return to the oil collection area to start the ISB process again.

In-situ burning can be more efficient than mechanical recovery under similar spill conditions because recovery devices, e.g., skimmers and temporary storage for skimmed oil, are not necessary with ISB. With ISB, there is no need for handling and disposal of the oil. However, ISB has its own logistical tradeoffs to be considered, e.g., enough fire boom available in the first 24 hrs. of the spill to conduct the number of burns necessary to remove all the oil that can be contained.

> ***Remember**, burn efficiencies, as used here, refer only to the volumes of the spilled oil that are contained in slick thickness required to support a successful burn, and are fresh enough to produce volatile vapors.
>
> Also, for this high level of efficiency to be achieved, all logistical requirements must be successfully implemented, generally, in the first 24 hours of the spill, which is a tall order.

A second advantage of *in-situ* burning is its relatively high burn efficiency. Studies have shown that 90% – 99% of the oil volume*, boomed and maintained at the required thickness, can be removed by burning under normal conditions. Case studies of actual burns, in particular on land, support this high efficiency. Burning is often considered on water and on land because responders need to prevent the oil from spreading into more sensitive areas or over larger areas and it offers the possibility of relatively complete removal of the liquid product if the logistics can be arranged. In several cases, an oil spill was burned on land because it was thought that the forecast for heavy rains would result in oil being flushed into sensitive areas. Burning in the early phase of the spill removes most of the oil before it can cause further damage on the water or on land.

A third advantage is that burning reduces the amount of oily wastes for collection and disposal. This factor will have a significant weight in the decision to conduct an ISB for remote or difficult to access areas.

Limited access might make mechanical or manual recovery impractical (or even harmful to the environment) to implement. Thus, ISB provides an option for oil removal where traditional response countermeasures are impossible to implement or would cause environmental damage. When a situation presents ideal conditions, ISB can significantly reduce the cost of an oil spill response and the environmental impact of the spill.

How Does Weathering of Oil Affect Potential ISB Issues?

Two weathering processes have the most impact on the success of *in-situ* burning: evaporation and emulsification. Evaporation is the loss of the more volatile fractions of the oil, so the remaining oil is less combustible. Evaporation affects the feasibility of both on-land and on-water ISB. For example, during an on-water spill, spilled oil that has undergone 1 – 2 days of evaporation may need to be concentrated into thicker slicks before being burned. The "rules of thumb" based on numerous experiments are:

- Fresh crude oils need to be at least 1 mm thick.
- Weathered (but not emulsified) crude oil slicks need to be 2 mm – 5 mm thick.

Emulsification is a very important weathering process for oil spills on water. It is the mixing of water droplets into oil, forming an emulsion. Many oils form emulsions containing 50% – 80% water. The presence of water in the emulsion prevents the oil from getting hot enough to burn. The water has to be boiled off first.

For emulsified oils, the heat applied while trying to start the burn essentially is boiling the water rather than heating the oil, and these circumstances result in an inefficient burn (Buist, 1998). Even when emulsions can be ignited, the fire burns more slowly and is easily extinguished. General guidelines are:

- Water-in-oil emulsions containing up to 12.5% water will not experience reduced effectiveness when burned.
- Emulsions containing 12.5% – 25% water will have reduced effectiveness of *in-situ* burning, particularly for extensively weathered oils.
- For emulsions containing more than 25% water, burning is typically not considered an option, although there are exceptions (unstable emulsions; waxy crude oils).
- ASTM (2003a) states that "typically oils with less than about 25% water will burn. Treatment with chemicals, i.e., emulsion breakers, to remove water before burning can permit ignition." Furthermore, ASTM states that there is "inconclusive evidence at this time on the water content at which emulsions can be ignited." Individual studies have successfully burned oil containing up to 70% water.

Section IV. When to Consider *In-situ* Burning

When to Consider *In-situ* Burning on Water

"On water" means spills floating on the ocean, coastal waters, estuaries, bays, freshwater lakes, and rivers. Decision-makers may consider using *in-situ* burning on floating slicks for the following spill conditions:

- **It is necessary to quickly remove large quantities of spilled oil to prevent its spread or impact to sensitive sites or over larger areas.**

  Burning can remove large volumes of oil quickly and at 90% – 98% efficiency for the corralled oil under ideal conditions. A 500 ft fire resistant boom one-third full of 18,000 gallons of oil is estimated to burn in 10 minutes, whereas recovery rates by skimmers and vacuum systems after the oil is contained are on the order of 200 – 300 gallons per minute. There are practical limits in maintaining these high removal rates (e.g., keeping the oil thick enough to sustain the fire, having to collect and separate patches of oil for each burn).

- **Oil recovery is limited by available skimming, storage, and handling capabilities.**

On-water mechanical recovery requires that skimming *systems* (e.g., boats, booms, skimmers, pumps, storage tanks, support barges, large crews for both operations and support, plus fuel for vessels, trucks, etc.) be available at the spill site. It may not be logistically possible to mobilize these systems at remote sites in time to be effective. Even under good conditions, skimmers collect more water than oil, necessitating large amounts of oily liquid storage on scene. The availability of on-water temporary storage often is cited as the most important limitation for mechanical recovery of oil on water. Furthermore, the collected oily liquid has to be transferred from the skimmer vessel to a storage tank or barge. The "turnaround time" for a skimmer to be offloaded and returned to the oil slick can be hours.

Skimmers normally do not operate at night because they need to be able to see the slicks and be directed to slicks by observers in aircraft. The number of gallons of oil that can be recovered in a 24-hour day is limited by these operational constraints.

In comparison, *in-situ* burning requires less logistics (fire-resistant boom, two boom-towing vessels, fewer people) and needs no on-site storage of oily liquids. It is possible to continue a burn at night under certain conditions, but not to safely collect and tow new patches of oil.

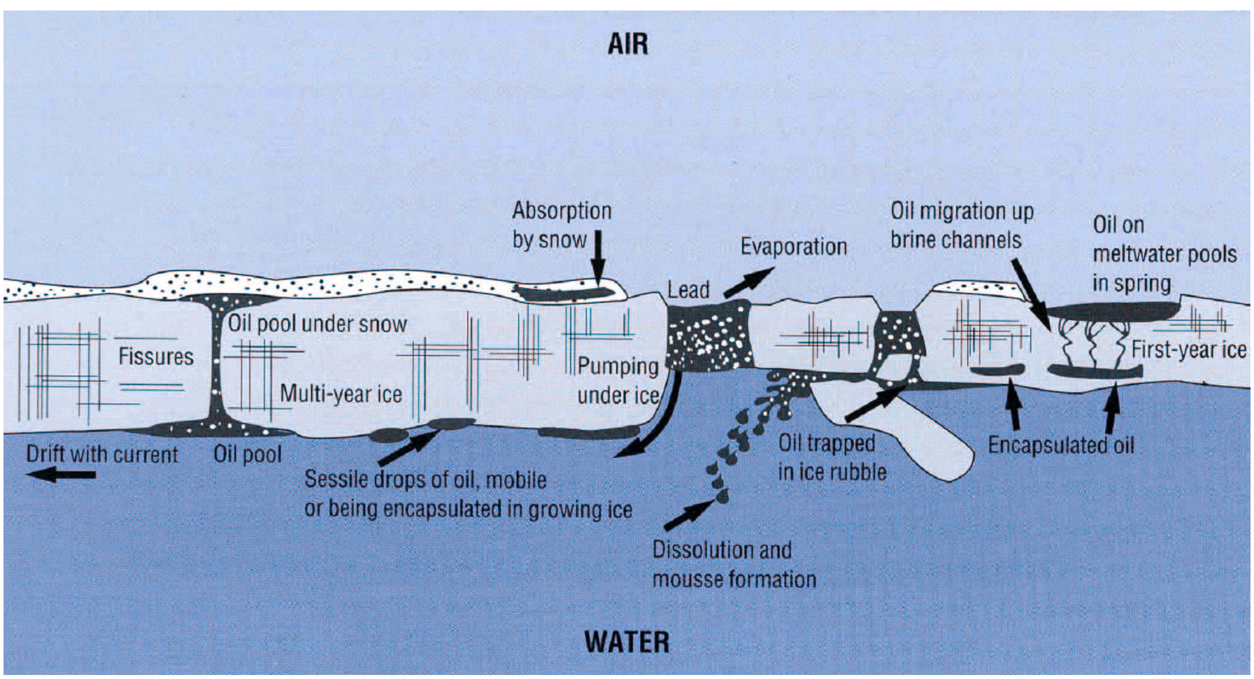


Figure 10. Oil in Ice Interactions. Adapted from Buist and Dickens, 2000.

- **The spill occurs in ice-infested waters where mechanical recovery is not effective.**

  Spills in icy conditions pose unique challenges for mechanical recovery (Buist and Dickens, 2000). Figure 10 shows the range of ways that oil behaves in ice-infested waters. The oil can be trapped under the ice, eventually being encapsulated in new ice that forms on the bottom of the ice. This oil can migrate through the ice, eventually forming pools on the surface. The oil can concentrate in "leads" or the cracks between large sheets of ice. It may not be safe for crews and equipment to work on the ice or in ice-infested waters. Once the oil is trapped in the ice, the only options are to remove the oiled ice to melt and separate the oil, or wait until spring breakup to recover the oil as the ice melts. Since the ice usually contains a very small amount of oil, responders often have to handle up to 100 times the amount of oil/ice, compared to open-water spills (Rivet, 2000). For example, it took 1,200 truckloads of oiled ice to clean up 65,000 gallons of a heavy fuel oil that was frozen in ice in the St. Lawrence River (Rivet, 2000).

  Oil spilled in broken ice will spread less and form thicker slicks than in ice-free waters. Oil spills on ice also tend to spread less (Buist, 2000). Responders can cut holes in the ice to allow the oil to float to the surface where it can be burned. Oiled snow can be burned if the oil content is at least 30%; otherwise more oil has to be added to ignite it.

What are the Optimal Site Conditions for Considering Use of *In-situ* Burning on Water?

This list provides a brief overview of the conditions when *in-situ* burning should be considered as an on-water response option.

- **The spill site is remote or sparsely populated.**

  The site should be at least a minimum of 0.5 – 1 miles (0.8 – 1.6 km) from populated areas and the wind should be blowing away from population areas to reduce impacts to sensitive resources and populations downwind from the smoke plume (ASTM, 1997). Smoke plume models have been developed to predict the downwind concentrations of smoke particles from *in-situ* burning of oil. Air pollution from ISB is usually short-lived and consists mainly of smoke particulates (Ferek et al., 1997). <u>Consult your local area/regional response plans for additional information on *in-situ* burning requirements.</u>

- **The winds are less than 20 knots (37 km/hr) and the waves are less than 3 ft (0.9 m) (USCG, 2003).**

  This wind speed is the upper limit at which a pool of oil can be ignited. Effective collection and containment of oil slicks in booms requires winds less than 15 – 20 miles per hour (24 – 32 km/hr) and waves less than 2 ft – 3 ft (0.6 m – 0.9 m).

  Decision-makers also have to take the presence of atmospheric inversions into account when planning a burn; atmospheric inversions can result in the smoke plume being trapped near the water surface/ground and potentially expose responders and the public. <u>Consult your regional/local area plans for further guidance on *in-situ* burning distance requirements; and consult with local air quality experts and meteorologists to ensure that the weather conditions are addressed.</u>

Density of the oil is defined as a measure of how heavy a specific volume of a solid, liquid, or gas is in comparison to water. The greater the density of a resultant burn residue, the more likely it is to sink.

- **The oil is a light to medium oil, with an API gravity greater than 32°API or an original (fresh) *DENSITY* less than 0.864 g/cm^3.**

  These oil types are easier to ignite, burn more efficiently, and create less residue. Oils that are heavier than this have a higher tendency to produce burn residues that may sink in seawater (SL Ross, 2002). Sinking of the residue would be of greater concern near shore and in sheltered water bodies. Sinking a small amount of residue is a lesser concern in open water settings where the residue could disperse over large areas.

- **The oil is relatively fresh and has not formed a stable emulsion.**

  Emulsified and weathered oils are difficult to ignite, burn slowly, and tend to extinguish quickly. They also burn less efficiently and create more residue.

- **Adequate containment, either natural containment or fire resistant boom, is available in time to conduct the burn within the window of opportunity and there is enough oil to sustain the burn.**

  The oil slick has to be at least 1 mm thick for fresh, volatile crude oils, and up to 10 mm (0.4 in.) for the heaviest, emulsified oils. Oil slicks tend to quickly spread out to less than 0.01 mm. They have to be contained and compressed into thicker slicks, either naturally (inside a tank, trapped in ice, trapped against debris in a river) or with fire resistant booms that are mobilized to the site.

When to Consider *In-situ* Burning on Land

"On land" includes a wide range of habitats, such as salt marshes, wetlands, ponds, grasslands, timberlands, and open fields. Decision-makers may consider using *in-situ* burning on land for the following spill conditions, as summarized in Dahlin, et al. (1999):

- **Access to the spill site is limited, making it difficult to get cleanup crews and equipment on scene.**

  The personnel and equipment for *in-situ* burning are logistically simpler than that required for mechanical or manual recovery, handling, storage, and disposal. Surrounding terrain (steep canyons, extensive wetlands) can restrict access to the spill site, or the ground may be too soft to support even foot traffic without causing significant damage (wet tundra, salt marshes, peat bogs). If there are no roads to a remote site, it might be possible to fly in personnel but not much equipment.

- **It is necessary to quickly remove spilled oil to prevent its spread to or impact to sensitive sites or over larger areas.**

  Burning can remove oil in hours, whereas manual or mechanical methods can take days to months. Timing can become critical during certain seasons, e.g., early spring, or near-term weather conditions. For example: forecasted rain is likely to flush oil from the spill site into sensitive areas; temporary containment structures are predicted to fail; or oil held in a small area by snow and ice will spread widely during a predicted thaw. These kinds of spill conditions trigger the need to rapidly remove as much oil as possible.

- **Options for transportation and disposal (temporary and/or permanent) of oily wastes are limited, so the amount of wastes generated must be reduced.**

  In-situ burning is efficient, with up to 90% – 98% efficacy for the volume of oil contained. During both manual and mechanical cleanup operations, large volumes of oily wastes are generated. The remoteness of a site from approved disposal facilities is an important factor in the decision to burn. Another consideration is weight restrictions on roads. Cleanup of a spill along the Trans-Alaska Pipeline changed from mechanical recovery to *in-situ* burning when weight limitations were placed on the road to the site with the arrival of the spring thaw.

- **The cleanup methods currently being used are not effective or could cause more damage.**

  Each cleanup method has an operational limit on how much oil can be removed. For example, most skimmers are not very efficient in recovering thin slicks; flushing cannot remove oil stuck on vegetation. Yet, further on-shore cleanup may be necessary to reduce the risk of impact to public health and the environment. Cleanup activities from some techniques (e.g., construction of access routes, vehicle traffic, foot traffic, blockage or diversion of water flow) can cause substantial damage to the environment. Less intrusive options like ISB need to be considered when environmental impacts need to be limited. Under the right conditions (see section below), *in-situ* burning can efficiently remove oil without significant damage to the habitat.

What are the Optimal Site Conditions for Considering Use of *In-situ* Burning on Land?

The following conditions provide a summary of the optimal conditions for the use of *in-situ* burning.

- **The spill site is remote or sparsely populated.**

  The site should be at least 0.5 – 1 miles (0.8 km – 1.6 km) from populated areas and the wind should be blowing away from population centers, to reduce exposure to sensitive resources and the public from the smoke plume (Ferek et al., 1997). Most previous spills where *in-situ* burning was conducted were in relatively remote areas.

  Decision-makers also have to take the presence of atmospheric inversions into account when planning a burn; atmospheric inversions can result in the smoke plume being trapped near the ground and potentially expose responders and the public. Consult your regional/local area plans for further guidance on *in-situ* burning distance requirements.

- **The winds are less than 12 mph (19 km/hr), and preferably lower.**

  Under calm winds, the smoke plume rises high in the air, reducing the public health risk. Low winds also allow better fire control.

- **The spill site is mostly unvegetated, such as dirt roads, ditches, dry streambeds, and idle cropland.**

  Without the concerns about impacting vegetation and wildlife habitat, the main concern would be to wildlife in the area. There have been several spills in crop lands during the winter when the fields were bare or had stubble from the previous year's crop. Complete removal of oil on dry ground is difficult without removing a lot of sediment. In these cases, burning was used to remove as much of the oil as possible, then the fields were tilled and fertilized. The land was farmed normally the next season (Dahlin et al., 1999). Natural bioremediation completed the oil removal.

- **Vegetation is mostly herbaceous (grasses).**

  Grasses as a group are much more fire tolerant than woody vegetation (e.g., shrubs and trees), although some woody species are also fire tolerant (e.g., have thick bark, re-sprout quickly after fire). Even if they are not killed outright by fire, trees generally take a long time to recover because of their slow growth rates compared to faster growing shrubs and grasses.

- **The vegetation is dormant (not during the growing season).**

  Studies of past spill sites have shown that *in-situ* burning is less damaging to the vegetation when it is not actively growing (Mendelssohn, et al., 1995). During the growing season, plants have used their underground food reserves to produce leaves, branches, seeds, etc. If the aboveground vegetation is removed by burning, plants might not have enough energy to produce new vegetation that can then generate enough food stores to regrow the next season.

  The U.S. Department of Agriculture maintains a database on the fire tolerance of different species of plants, including how they respond to fire at different growing and seasonal periods, to support use of prescribed burns as a management tool. It is called the Fire Effects Information System (FEIS) and is available at: www.fs.fed.us/database/feis/welcome.htm. This information can be used to determine how plants will respond to burns without the added fuel of oil. It is unknown whether the effect of an ISB would be different than that of a natural or prescribed burn.

- **At wetland sites, the soil is covered by a layer of water.**

  A water layer provides protection in several ways. It provides an insulating layer that protects plant roots from the heat of the burn. It may prevent organic soils from catching on fire. Water prevents oil from soaking into the soil before and during the burn. Recent controlled experiments with potted fresh- and saltwater marsh grasses showed that 1 in. – 4 in. (2.5 cm – 10 cm) of water was enough to protect the roots from heat stress (Bryner et al., 2003; Lin et al., 2002). From actual burns in oiled wetlands, the rule of thumb is that a layer of water is preferred, but saturated soils are also considered good sites.

- **The burned wetland will not be flooded with high water levels right after the burn.**

  This is a lesson learned from both *in-situ* burning sites and use of prescribed burning as a land management tool. When the aboveground vegetation is burned away, the roots have to get oxygen from the soil until new vegetation emerges. If the burn site is flooded by water immediately after the burn, the oxygen in the waterlogged soil is reduced to the point that the plants eventually die.

- **Snow and ice provide natural containment and protection.**

  Snow can act as a natural sorbent, preventing the spread of the oil. In Arctic settings, *in-situ* burning on land is considered viable if there is a layer of ice covering the vegetation to protect it from heat damage. Ice also protects the soil from thawing, which would allow the oil to penetrate into the thawed soil.

- **The oil type is a light-to-medium crude oil or refined product.**

  Lighter oils burn more efficiently and leave a smaller amount of residue to recover. Heavy oils burn less effectively and can leave a thick, sticky residue that requires extensive cleanup.

Additional Considerations

Impacts to Plants from the High Temperatures Present during *In-situ* Burning

Many types of vegetation are burned regularly as part of habitat and wildlife management. These "prescribed burns" are an intentional fire ignited to meet specific habitat management objectives. There is a field of science called fire ecology that studies how plants respond to fire so that this information can be used in the design of prescribed burns. Managers use fire to maintain certain types of plants as well as to eliminate exotic or nuisance plants. As noted above, FEIS is a major source of the knowledge gained from prescribed burns. However, there are concerns about how this information should be used when adding oil to the burn conditions. Oil adds fuel that will increase the burn temperature and duration (compared to a burn without oil). A hotter and longer burn can heat up the soil to temperatures that can kill plants.

Because of the concern about keeping the soil temperatures within safe limits, it is recommended that *in-situ* burning in natural vegetated areas (e.g., wetlands, tundra) be conducted when there is a layer of water or ice over the ground or the soils are water-saturated. Lin et al. (2002) conducted experimental burns of oil using plots of salt marsh and varying the thickness of the oil (and the duration of the burn) with different water depths over the plants. They monitored the temperature in the soil at different depths during the burns. The objective was to determine how much water was needed to protect the plant roots from heat damage. They found that the plants died when the soil temperatures were above 60°C (140°F). In their experiments, the soil temperatures stayed below 60°C when there was at least 2 cm of water over the plants, but not when the water level was even with the plants roots or below the plants roots. Longer burns heated the soils to higher temperatures. Soil temperatures at real *in-situ* burning sites might be different, but these data support the guidelines that water and ice layers are important for protecting plant roots from getting so hot that they die.

Burning in High Organic Soils

Burning of oil in soils with high organic content (e.g., peat) is of particular concern for several reasons. The peat itself could catch on fire and burn beyond the oiled area. Peat burns would be of concern where the water table was low and the peat was de-watered. Peat is highly permeable and oil can penetrate deeper into the peat because of the burn. Also, organic soils have low oxygen and nutrient levels, so degradation rates of oil residue would be very slow. However, oil spills in these kinds of setting are very difficult to clean up using manual or mechanical methods, making *in-situ* burning a viable option to minimize the overall impact. Still more information is needed on when to use *in-situ* burning in peaty soils.

Potential Effects of the Fire on Overhead or Adjacent Structures

When an oil spill occurs, the potential collateral damage to adjacent structures from an ISB must be considered. Even when spills are in remote locations, there may be overhead powerlines or pipelines to consider. Pipelines often parallel other utility or transportation corridors. Safe distances from facilities, supporting infrastructure and other types of structures, such as transformer stations, bridges, and buried cables, need to be considered when evaluating the risks from an ISB.

Public Notification and Air Quality Approvals

In addition to logistical and technical requirements and considerations, decision-makers have to obtain approvals from state and/or local air quality officials to conduct the burn. Also, the public will probably need to be notified of the intent to burn, the intended burn schedule, possible evacuations, and the procedures to be taken by the affected public. Obtaining the approval for an *in-situ* burn is a substantial action when considering a burn.

Section V. Operational Issues for *In-situ* Burning

Equipment and Experience Needed for Conducting *In-situ* Burning

Table 1 lists the range of equipment that might be needed for *in-situ* burning on land and water.

Table 1. Equipment That Might be Needed for *In-situ* Burning Operations on Land and on Water.

On Land	On Water
Ignition source(s)	Fire resistant boom in 300 – 500 ft [100 m – 150 m] sections*
Fire-fighting capability	Two towing vessels*
Equipment to construct firebreaks or containment dikes	Ignition source(s)
Hand tools and sorbents for burn residue recovery	Hand tools and sorbents for burn residue recovery
	Spotter aircraft
	Support vessel for fuel, supplies, and personnel
	Repair parts for fire resistant boom*

* Not required for burns in water with high concentrations (> 60%) of ice cover.

On Water

> **REMEMBER**:
>
> On-water ISB requires RRT concurrence, plus approval from air quality officials, except where pre-approval zones/conditions have already been established.

In-situ burning on water requires more extensive logistics than burns on land (see Table 1). The oil has to be contained to a minimum thickness to start and maintain the fire. Fire resistant boom and vessels for towing the boom are required unless there is natural containment (e.g., in ice, trapped in debris). Spotters in aircraft usually direct the boat crews to the oil. Once the oil is contained in a safe place, an ignition source is needed. Generally, fire-fighting equipment is not required because the fire can be put out by letting one side of the boom go so that the oil becomes too thin to sustain the fire. Dip nets and other hand tools will be needed to recover any floating burn residue. Depending on how far offshore the burn is located, there may be a need for support vessels.

Skilled boat operators are needed to tow the boom in a "U" configuration at speeds that concentrate, but do not lose the oil by going too fast. After ignition, the burn can be controlled by towing the boom at the speed needed to keep it at the maximum thickness (typically about 0.5 knots). For spills that are naturally contained on water (e.g., on or between ice floes), an ignition source may be used to start the burn once the spill has been located and approvals obtained. Due to access issues in ice-covered waters, the Helitorch may be the preferred ignition source under these conditions.

On Land

> **REMEMBER**:
>
> On-land ISB requires RRT concurrence, except where pre-approval zones/conditions have already been established.

Many times, the only equipment needed to burn a spill on land is an ignition source. As discussed previously, ignition sources range in sophistication from matches to Helitorches that are suspended under helicopters. Spills on land often are naturally contained, but dikes can be constructed to contain the oil or act as firebreaks. Firebreaks are an important component of every burn. There are guidelines for minimum dimensions depending on the site conditions. Fire-fighting equipment and skilled firefighters are required in most cases to be able to put the fire out if it gets out of control.

Consultation with personnel who are skilled in conducting prescribed (intentional) fires is also recommended for burning of oil on land. State and federal land managers often use burning as a land management tool. These prescribed fire practitioners know how to safely conduct burns to achieve desired results. They know from experience the best conditions to support a successful burn. These specialists can assist in evaluating the potential impacts of the planned burn on vegetation and wildlife.

Pre-burn planning

The first steps toward using *in-situ* burning at an oil spill are obtaining approval to conduct the burn and developing a burn plan. Checklists have been developed (see example on page 50 of this volume) to provide an easy way to compile the information needed by decision-makers. The checklist documents should contain the incident-specific information that support the decision whether *in-situ* burning should be approved, including, but not limited to:

> **REMEMBER**:
>
> Consult your local area/ regional contingency plan to determine if the region where ISB is being considered has a similar checklist for ISB.

- Nature, size, and type of product spilled,
- Weather: current and forecasted,
- Oil trajectories for on-water spills,
- Evaluation of other response options,
- Feasibility of using *in-situ* burning (wind speed, sea state, oil type, weathering, thickness, visibility),
- Potential impacts to habitats and wildlife: consultations with natural resource agencies on potential impacts and tradeoffs,
- Equipment and personnel requirements and availability,
- Detailed burn plan (see details below),
- Health and safety plan (including public notifications, site security, and fire-fighting capabilities), and
- Monitoring plans, as needed (air, water, sediments, vegetation, wildlife).

The burn plan should include information on:

- Amount of oil to be burned,
- Area to be burned,
- Ignition methods,
- Estimated duration of the burn,
- Tactical assignments of resources (for specific personnel and equipment),
- Results of smoke plume trajectory modeling, if available,
- Plan for additional burns,
- Methods for terminating the burn,
- Specified monitoring endpoints and conditions that will be measured to determine the need for burn termination, and
- Methods for collecting burn residues.

Incident-specific Issues for *In-situ* Burning

Special issues, specific to the site conditions, may need to be addressed, in addition to the above information on the checklist. Issues that have been identified from previous spills are discussed below.

1. Potential for changes in the type of vegetation that grows back. Plants respond differently to burning, depending on the species, time of year, temperature and duration of the burn, soil moisture, etc. Fire ecologists should be consulted on the potential for changes in the plant community at sites that are important wildlife habitats.

2. Control of herbivores. New growth at burn sites can attract deer, rabbits, and other herbivores. It may be necessary to protect the site from overgrazing that can slow recovery.

3. Erosion control. Loss of vegetation may lead to erosion during heavy rains. Temporary ground covers may be needed until vegetation is re-established.

4. Consultation with Federal agencies under the Endangered Species Act. If the proposed burn could impact any threatened or endangered species listed under the Endangered Species Act (ESA), then the appropriate Federal agency must be contacted and a consultation initiated. Under the Endangered Species Act Memorandum of Agreement (MOA), a consultation (informal, formal, or emergency) must be conducted when response actions will be taken in areas where protected resources are potentially impacted (USCG, et al., 2001b). This is required under Section 7 of the ESA, and the MOA requires that specific paperwork be filed and actions documented throughout the spill.

   During the emergency phase of a spill response, an emergency consultation can be done quickly. The FOSC submits a burn plan to the U.S. Fish and Wildlife Service or National Marine Fisheries Services ESA personnel. ESA personnel and other stakeholders review the burn plan and determine whether any listed species are likely to be affected, and if the plan minimizes to the degree possible any negative impacts. The agency may recommend additional actions to further protect listed species.

5. Actions to enhance oil weathering. Residual oil (both unburned oil and burn residues) can persist in the soils after the burn and final cleanup activities are terminated. These areas can be fertilized, watered, and tilled to promote microbial degradation of the remaining oil. This approach is feasible where tilling would not disturb established vegetation.

   A second strategy to enhance oil weathering is through phytoremediation, which is the use of plants to promote the breakdown of the oil in the soil. Waterlogged soils often have low oxygen and nutrients, which can slow degradation. Plants can add oxygen to the soil through their roots. The roots also provide a surface on which microbes can concentrate. Several studies have documented increased oil degradation rates in oiled wetland soils with plants compared to unvegetated soils and fertilizer alone (Lin and Mendelssohn, 1998; Wright et al., 1997). If the soils remain significantly oiled, re-planting may be considered as a final strategy to promote rapid re-vegetation and enhanced oil degradation.

Monitoring

There are different types of monitoring that can be conducted at an *in-situ* burning site, depending on the spill and burn conditions.

Pre-burn Monitoring

It is important to document the site conditions immediately before the burn. The objective is to be able to correlate the burn conditions with the effectiveness of the burn and the rate of habitat recovery. Historically, documentation of the spill conditions prior to the burn has been poor, preventing complete evaluation of the effectiveness and effects of the burn as a cleanup technique. Listed below are suggested pre-burn monitoring parameters for burns on land:

- Depth of water over the ground, if any,
- Thickness of oil on the water or ground surface,
- Depth of oil penetration into the ground,
- Wind speed and direction,
- Air temperature,
- Samples of the source (fresh) oil and the oil right before the burn,
- Samples of sediment and water right before the burn, and
- Dominant plant species present and affected by the oil.

Photographic evidence should be collected for the ISB site prior to the burn. All photographs should be recorded immediately and the approximate location of the photograph and its direction should be marked down on a map to assist in taking comparative photographs following the burn. Additionally, consider taking some oblique aerial photographs of the oiled area prior to the burn, to document the site conditions.

Health and safety of response personnel and the public are always a primary concern. Prior to the start of the burn, the site should be surveyed to make sure that no one has entered the burn zone, that firebreaks are in place, that firefighting equipment is deployed according to the plan, and that the site conditions meet the plan requirements. For example, if the wind speed is too high, the burn should be delayed until the winds drop. If the wind direction has changed so that the smoke could affect responders or the public, again the burn should be postponed until safe conditions can be established.

Monitoring during the Burn

During the burn, air quality monitoring is conducted when there is a human-health risk associated with the burn. The next section describes the Special Monitoring of Applied Response Technologies (SMART) monitoring protocols that focus on monitoring of air quality at a burn. Monitoring during the burn can also include:

- Duration of the burn, and
- Wildlife impacted during the burn.

SMART

The SMART document can be downloaded from: www.response.restoration.noaa.gov

With the acceptance of *in-situ* burning as a spill response option, concerns have been raised regarding the possible effects of the particulates in the smoke plume on the general public downwind. Special Monitoring of Applied Response Technologies (SMART) is designed to address concerns regarding the use of *in-situ* burning (and dispersants) as a response tool and better aid the Unified Command in decisions related to initiating, continuing, or terminating *in-situ* burning.

In general, SMART is conducted when there is concern that the general public may be exposed to smoke from the burning oil. Whether or not monitoring is required depends on the predicted trajectory of the smoke plume and if it will reach population centers and exceed safe levels of smoke particulates at ground level. If impacts are not anticipated, monitoring is not required

(USCG et al., 2001a). Since *in-situ* burning has a narrow window of opportunity, it is imperative that monitoring teams are alerted of possible *in-situ* burning and SMART operations as soon as burning is being considered.

For large-scale burns, SMART recommends that three monitoring teams be established to use data collecting equipment such as particulate monitors and global positioning systems to monitor air quality around the burn and downwind. These monitoring teams are deployed at designated areas of concern to determine concentrations of particulates before the burn starts. During the burn, sampling continues and readings are recorded. Sampling should also be conducted for some time (15 min. – 30 min.) after the burn and smoke plume have dissipated.

Monitoring locations are dictated by the potential for smoke exposure to human and environmentally sensitive areas. Monitoring locations should be flexible and determined on a case-by-case basis. In general, one team is deployed at the upwind edge of a sensitive location and a second team is deployed at the downwind end of this location. Both teams remain at their designated locations, moving only to improve sampling capabilities. A third team is more mobile and is deployed at the discretion of the burn coordinator.

When addressing particulate monitoring for *in-situ* burning, the National Response Team (NRT) emphasizes that concentration trend, rather than individual readings, should be used to decide whether to continue or terminate the burn. For SMART operations, the time-weighted average (TWA) generated by the particulate monitors should be used to determine the trend. The NRT recommends that burning not take place if the air quality in the region already exceeds the National Ambient Air Quality Standards and if burning the oil will add to the particulate exposure concentration.

Immediate Post-burn Monitoring

As soon as it is safe, the burn area should be inspected to record the effectiveness of the burn and assess any need for further burning. On land, monitoring activities could include:

- Documentation of the type and extent of burn residue,
- Samples of the post-burn residue,
- Depth of oil penetration into the substrate,
- Record of the type and number of animals killed by the burn, and

- Assessment of the need to implement erosion control until vegetative cover is re-established.

Again, photographic evidence should be collected for the ISB site following the burn.

Benzene, toluene, ethyl benzene and xylene (BTEX) compounds are volatile organic compounds that are present in light refined products and crude oils. Their presence after a burn would indicate incomplete combustion of some of the oil. The BTEX compounds are toxic to many organisms.

Total Petroleum Hydrocarbons (TPH) measurements are used to document the residual oil content in sediments and monitor recovery sites.

Diesel Range Organics (DRO) are a subset of the TPH measurement that measures petroleum hydrocarbons in the diesel range, up to carbon number C-28.

Polycyclic Aromatic Hydrocarbons (PAH) are multiple ring organic compounds that weather slowly. They are monitored in rivers and waters following an ISB. These byproducts of incomplete combustion include some of the most potent carcinogens.

Post-Burn Data Gathering

States have different post-burn monitoring requirements for gathering data on the effectiveness and impact of the burn. This data can be used to make final cleanup decisions on the site, e.g., how clean is clean, as well as provide important lessons learned for future decision-making. For burns on land, data gathering can include:

1. Water and sediment quality. Samples of water and sediment from the burn site and reference sites are collected over time until the burn site samples meet state standards or reach the same levels as the reference sites. Target analyses will depend on the oil type and could include benzene, toluene, ethyl benzene and xylenes (***BTEX***) compounds, ***TOTAL PETROLEUM HYDROCARBONS (TPH), DIESEL RANGE ORGANICS (DRO), and POLYCYCLIC AROMATIC HYDROCARBONS*** (PAH). Sediment samples could be collected in coordination with vegetation monitoring, as discussed below.
2. Aerial photography. Some states require that aerial photography of the burned area be collected shortly after the burn (to document the extent of the burn) and at specific intervals after the burn, to document recovery of the vegetation. For example, Louisiana requires vertical aerial photographs right after the burn and during the next two growing seasons.
3. Vegetation monitoring. For vegetated sites, study plots or transects can be established in an 1) unoiled and unburned (reference) area; 2) oiled and burned area; and 3) if available, oiled and unburned area. Measurements at these study sites could include percent vegetative cover (total and by dominant species) and stem density. Alternatively, time-series photography could be collected to document the recovery of the site. The best approach is to repeat the photography from the same position and view.

Required Authority

For burns on land and on state waters (including offshore water to the state boundary which is generally 3 miles from mean low water), approval to burn from the appropriate state agencies is required. The state agency that regulates air quality needs to be part of the approval process. Members of the Regional Response Team (RRT—EPA RRT co-chair, state RRT representative, DOI and NOAA RRT representatives, as well as others agencies that may be directly affected), must provide for concurrence or establish pre-approval zones for an *in-situ* burn whether or not an accelerant (burning agent) is used.

The RRT will allow, with permission, an accelerant (a small amount of lighter hydrocarbon applied to a limited area to start a small fire that generates enough heat to volatilize the larger pool of oil and ignite the entire slick) to be used. However, the RRT will virtually never allow an accelerant to be applied to the entire slick to make it burnable if the oil would not support combustion under normal circumstances. Many regions require that the RRT be notified of the plan to conduct an *in-situ* burn. Notification of the RRT is strongly recommended in all oil spill responses where *in-situ* burning is used as a response method.

As of August of 1998, 19 States had agreements for pre-authorized use of *in-situ* burning in the coastal zone (see Figure 11). Only one state (Maine) had pre-authorization for the use of *in-situ* burning in the inland zone, and 14 states consider *in-situ* burning on a case-by-case basis in the inland zones, using it often to address on-land spills. <u>Consult your local area/regional response plans to determine the extent of pre-authorization and notification requirements.</u>

Section VI. In-*situ* Burning Health And Safety Concerns

OSHA Requirements for ISB Personnel

The U.S. Occupational Safety and Health Administration (OSHA) developed specific requirements for training of all oil and hazardous materials spill responders under the Hazardous Waste Operations and Emergency Response standard (HAZWOPER) in 29 *CFR* 1910.120. These requirements also apply to responder personnel participating in a burn (OSHA, 2001). OSHA is responsible for assuring safe and healthful working conditions for response personnel; this would include exposure to combustion

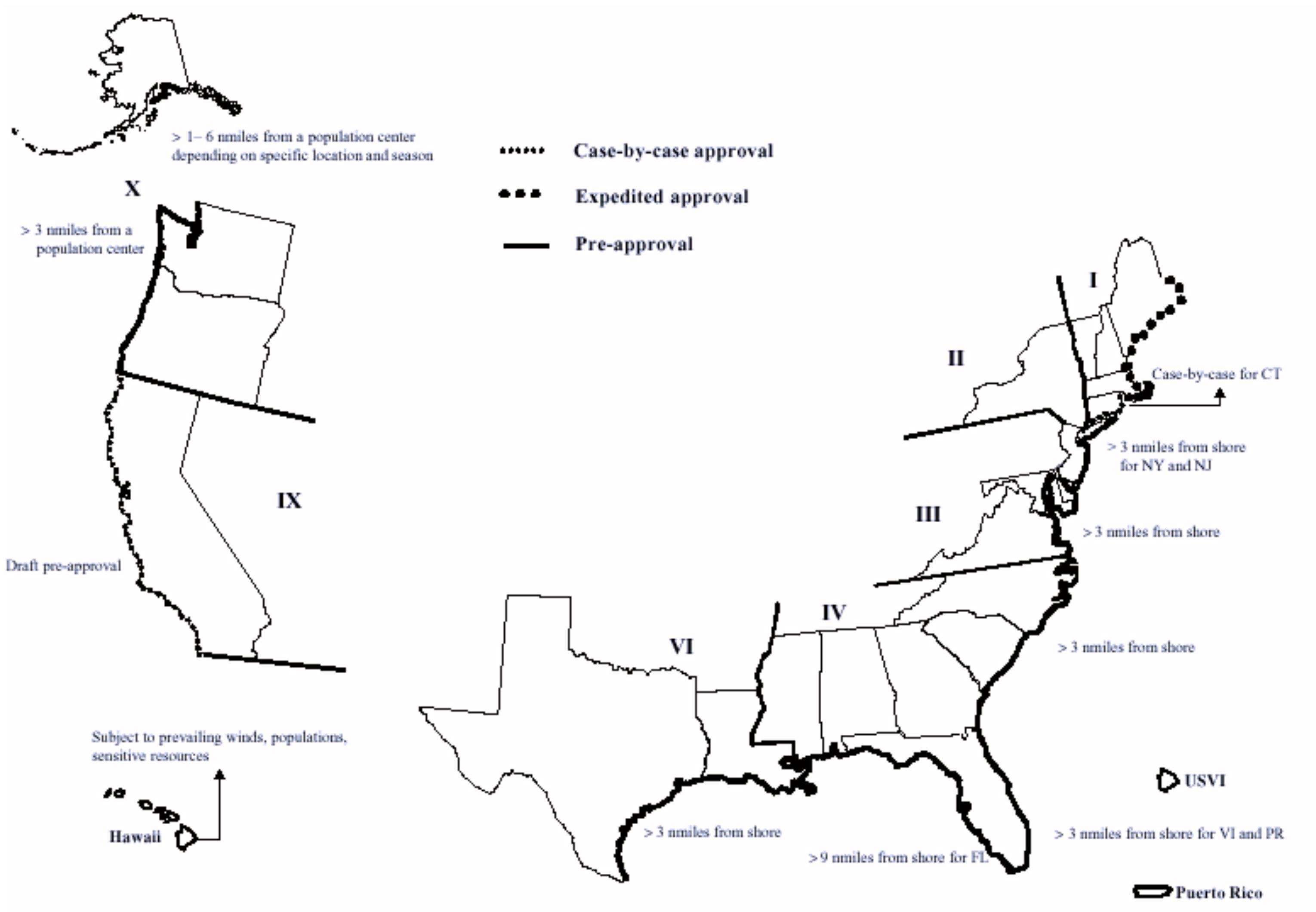


Figure 11. *In-situ* Burn Pre-approval Status for the Coastal States of the U.S. Taken from: http://www.uscg.mil/vrp/

particulates from a burn. Under the *Clean Air Act,* EPA is required to set limits on how much of a pollutant can be in the air anywhere in the United States—OSHA enforces these limits.

For regulating the exposure to pollutants, the EPA Office of Air Quality Planning and Standards has established National Ambient Air Quality Standards (NAAQS) for six principal pollutants considered harmful to public health and the environment. These pollutants (also referred to as Criteria Air Pollutants) include: carbon monoxide, lead, nitrogen dioxide, Particulate Matter < 10 μg (PM-10), Particulate Matter < 2.5 μg (PM-2.5), ozone, and sulfur oxides. The NAAQS standards take into account both ambient air quality (pre-burn) and the contaminant levels added by the burn plume.

For an ISB, the issue of greatest health and safety concern involves the ISB response personnel's exposure to the PM-10 components of the burn plume. In all cases, exposure to the smoke plume should be avoided. Exposure to the PM-10s in the smoke plume can affect human health; it is generally the long-term exposure over months to years to PM-10s that affects health. However, short-term exposure to high concentrations (such as is found in an ISB smoke plume) can aggravate symptoms in sensitive individuals with existing heart or lung ailments (see Figure 12).

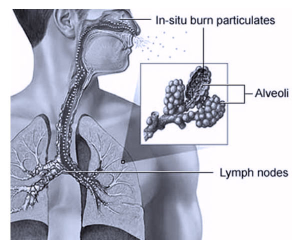


Figure 12: Example of PM-10 Inhalation

ISB Safety Plans

As a pre-incident planning function, response agencies should develop generic site safety plans composed of checklists and fill-in-the-blank formats to facilitate rapid incident-specific data entry. During emergency response, site safety plans must be flexible and easily adaptable in order to keep pace with the dynamics of spill specific conditions and changes in the situation. Generally, response agencies develop site safety plans that consist of a generic core portion which captures required general oil spill site-safety elements along with a repository of incident-specific attachments to access quickly as the incident dictates.

In the U.S., individual RRT ISB plans address safety as a primary consideration for the feasibility of conducting *in-situ* burning. Some RRT plans contain statements requiring that the party seeking approval submit an OSHA-compliant site safety plan to the Federal On-scene Coordinator (FOSC). Other RRT plans incorporate site and worker safety issues into their Applications for Approval or Operational Checklists.

Section VII. In-situ Burning Case Histories And Lessons Learned

The best way to learn about the effectiveness and effects of *in-situ* burning is to study previous cases where it was used. Oil spill response is a very empirical field; often we know what works well, or not, because we have tried it. Unfortunately, documentation of most *in-situ* burns has been poor. Dahlin et al. (1999) found that some states have frequently allowed burning of small spills (less than 5 barrels or about 200 gallons), but adequate documentation only exists for 31 cases of *in-situ* burning on land. From these cases, Dahlin, et al., (1999) found that:

- Burns were conducted most frequently in marshes and open fields,
- Burning was often a final cleanup method used after mechanical or manual removal was terminated,
- Nearly half of the burns were of spills less than 400 gallons, though for many cases the volume of oil burned was unknown (13 of 31 cases),
- The most common type of oil burned was light-to-medium crude oil (22 of 31 cases), and
- In only one case was a heavy crude oil burned, and it was reported to have not burned well.

Dahlin, et al., (1999) also reviewed the literature on fire ecology and prescribed burns to summarize the lessons learned from the use of burning without oil on plants. Mendelssohn, et al., (1995) conducted a literature review of wetland sites where *in-situ* burning of oil spills was used, and visited six sites for follow-up monitoring of the vegetative recovery. To learn more about the medium-term recovery (1 – 3 years) at *in-situ* burn sites on land, API sponsored follow-up studies of four *in-situ* burn sites (Michel et al., 2002). These three studies (Dahlin et al., 1999; Mendelssohn et al., 1995; and Michel et al., 2002) provide the best information available to-date on use of *in-situ* burning on land.

Case Studies of *In-situ* Burning on Land

Case Study No. 1—Refugio County, Texas

Figure 13. Refugio County, TX burn.

The oil was spilled from an underground pipeline and spread down slope into a wetland containing brackish marsh species that was used to graze cattle. The oil flowed down the numerous cattle paths. Trenches were dug near the leak to intercept the oil. The oil continued to spread into the wetland, eventually affecting 11 acres. Because the oil could not be contained, the remaining oil was burned. A layer of water 4 in. – 8 in. (10 cm – 20 cm) deep covered the ground. Fire officials ignited the oil, which burned intensely over 5 – 6 acres for 4 hours. Oil removal by the burn was estimated to be 90%. After the burn, standing oil remained only in the deeper tracks. Oil in fringe areas was burned the next day. Many crayfish in the burned area were killed, but many also survived. The landowner did not allow follow-up studies (summarized from Clark and Martin, 1999).

Case Study No. 1: Refugio County, Texas

Spill Date: 12 May 1997

Oil Type: Refugio Light and Giddings Stream crude oils (probably API = 41°)

Spilled Volume: 500 – 1,000 bbls (21,000 – 42,000 gal).

Burned Volume: Not determined (Martin, pers. comm. 2003)

Habitat: Brackish wetland used for cattle grazing

Figure 14. Refugio County, TX after the burn.

Figure 15. Oil/residue Remaining after the Burn, Refugio County, TX.

Case Study No. 2—Brunswick Naval Air Station, Brunswick, Maine

Case Study No. 2: Brunswick Naval Air Station, Brunswick, Maine

Spill Date: 26 March 1993

Oil Type: JP-5 aviation fuel

Spilled Volume: 1,512 bbls (63,500 gallons)

Burned Volume: 500 bbls (21,000 gallons)

Habitat: Freshwater pond and adjacent wetlands

Figure 16. Brunswick Naval Air Station Burn.

Figure 17. The Site of the Brunswick Naval Air Station Burn, 4 to 5 Months Later.

The oil was spilled from a pipeline valve at a newly-constructed tank farm. The oil was naturally contained in the pond by extensive ice and about 3 ft (1 m) of snow. About 2/3 of the oil was recovered by vacuum trucks over one week. The rest of the oil was not accessible, and it was burned 8 days after the spill. The oil burned for 5 hours, and smaller burns were conducted over the next two days. About 11 bbls (460 gal.) of oil remained after the burn (98% burned). There was no burn residue, only unburned oil. Studies of the vegetation, fish, birds, mammals, benthic community, water quality, and sediment quality were conducted the following summer. The results showed normal species abundance and distribution. Sediment samples showed elevated oil levels in a low flow area of a connected stream, but none in the burned areas.

Case Study No. 3—Chiltipin Creek, Texas

Figure 18 : Chiltipin Creek, TX burn

Spill Date: 7 January 1992

Oil Type: South Texas Light crude oil (API = 37°)

Spilled Volume: 2,950 bbls (124,000 gallons)

Burned Volume: 1,150 bbls (48,000 gallons)

Habitat: High-elevation salt marsh

The oil was spilled from an underground pipeline, eventually affecting 25 acres of a high marsh dominated by salt grass, salt wort, and shoregrass. The ground was saturated from days of rain, and access to the site was difficult. Responders used vacuum trucks to recover oil for 4 days. The oil in the marsh continued to spread below the dense vegetation. The forecast called for more rain, and it was feared that the oil would continue to spread and reach the Arkansas River, which was about 1,500 ft (460 m) from the leading edge of the oil. The oil in the marsh was 1 mm – 3 mm thick. After ignition using mineral spirits, the fire burned for 21 hours, removing 80% – 85% of the oil. Three remaining pools of oil were burned the next day. The marsh was covered with a residue described as an asphaltic, taffy-like material that was very sticky. Heavy rains fell that night, flooding the marsh. Cleanup workers, working on planks in the marsh, used sorbents to recover as much of the residue as possible over the next 15 days (summarized from Gonzalez and Lugo, 1995).

Researchers monitored the recovery of the burned marsh for 5 yrs. They studied the vegetation, fiddler crab population, animals in small ponds, bird use, and sediment contamination. Right after the burn, the marsh was severely impacted. The sediments still contained a lot of oil, with levels averaging 1,000—2,500 ppm over the 5-year study period. After 2 years, vegetation cover was back, but most of the vegetation was salt grass, a pioneering species rather than the normal mix of species indicative of a healthy marsh. Five years later, about 20% of the burned marsh was bare, compared to 4% for a reference marsh. The researchers concluded that the intensity of the burn and/or the oil penetrating into the roots had killed most of the vegetation. They

Figure 19. Chiltipin Creek 2 years after the initial burn.

also concluded that the burn probably allowed a more rapid recovery compared to mechanical or "do nothing" approaches (summarized from Tunnell, et al., 1997 and Hyde, et al., 1999).

Case Study No. 4—Mosquito Bay, Louisiana

Case Study No. 4: Mosquito Bay, Louisiana

Spill Date: 7 January 1992

Oil Type Condensate (a very light crude oil)

Spilled Volume: >1,000 bbls (>42,000 gallons)

Burned Volume: >500 bbls (>21,000 gallons)

Habitat: Salt and brackish marsh, intertidal

The release was from a pipeline leak in the interior of a marsh island. The vegetation trapped the bulk of the condensate (a very light crude oil that was almost like diesel). Manual removal was attempted for a week and was causing considerable damage to the vegetation from foot and airboat traffic. The tidal range was 1 ft. — 2 ft. (0.3 m—0.6 m), and at low tide the oil stranded on the marsh surface and soaked into fiddler crab burrows. Two areas were burned 6 and 7 days after the spill. At the time of the burn, oil had penetrated up to $^{3}/_{4}$ in. (2 cm) into the marsh soils via crab burrows and root cavities. Free oil was up to 4 cm thick, pooled on the water surface and in burrows, though there were extensive areas where the oil thickness was on the order of 1 mm. Although 12 acres were oiled, 98 acres of marsh were burned before the fire went out. The fire jumped the rough firebreaks created by running airboats back and forth over the vegetation. The marsh had not been burned in several years, thus there was abundant fuel to keep the fire going outside the oiled area.

Figure 20. The Mosquito Bay, LA burn, 1 hour after the first burn ended. The firebreak is barely discernable as an arc around the small bay. The marsh burned to the downwind water's edge in most areas.

Approximately 90% – 95% of the surface oil was estimated to have burned. There was no burn residue. Free oil that had not burned remained pooled in the burrows. After 6 months, nearly all of the oil in the sediments had degraded.

Aerial photography and ground studies were conducted the first year after the spill and burn. The vegetation in the areas of the thickest oil layers died, whereas areas of light oiling and no oil (but burned) re-grew quickly. Burning obviously did not reduce the toxicity of the light crude oil that covered the marsh vegetation for 6 – 7 days. Burning did, however, prevent the further spread of the oil to other areas and additional damage from manual cleanup efforts (summarized from Michel et al., 2002).

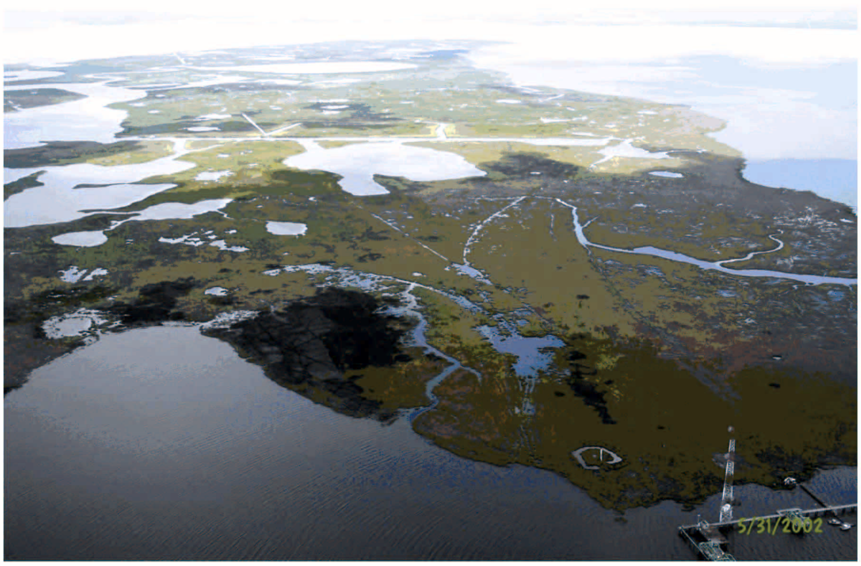


Figure 21. The Mosquito Bay, LA Burn, 13 Months Later.

Case Studies of *In-situ* Burning on Water

Fingas (1999) listed 40 known spills and experiments where *in-situ* burning on water was conducted over the period 1958 – 1998. To this list, we can add 3 others, for a total of 43 intentional *in-situ* burning on water events (spills where the oil ignited on its own are not included). Of these, 13 were actual spills; the other 30 were experiments. Of these 13 actual spills, 4 were in ice, and 2 were attempts to burn the oil inside the holds of the ship (Torrey Canyon and New Carissa). Burning of uncontained slicks was attempted at 4 spills, showing that fresh thick slicks will burn right after release but not thin slicks. The most recent on-water *in-situ* burning at a spill was the 1989 test burn during the Exxon Valdez (Allen, 1990), which was the first time fire-resistant boom was used at a spill. The 1993 Newfoundland Offshore Burn Experiment (NOBE) was the largest scale open-water experiment. So, these two events are used as case studies of *in-situ* burning on water.

Case Study No. 5—Exxon Valdez Test Burn, Prince William Sound, Alaska

Case Study No. 5: Exxon Valdez Test Burn, Prince William Sound, Alaska

Spill Date: 24 March 1989

Oil Type: North Slope crude oil (API = 29°)

Spilled Volume: 257,000 bbls (10.8 million gallons)

Burned Volume: 350-700 bbls (15,000-30,000 gallons)

A test burn was conducted during the evening of the second day following the spill. An estimated 15,000 – 30,000 gallons of crude oil was collected by towing 450 ft (140 m) of fire boom in a U configuration. The oil was ignited with gelled gasoline in a plastic baggie that was floated into the oil in the boom because it was dark by the time of the burn. The burn lasted 1 hour and 15 minutes. The seas were calm. The area of burning oil was controlled by adjusting the speed of the towing vessels. There was no unburned oil remaining. There was about 100 ft^2 (~9 m^2) of burn residue of taffy-like consistency that was 4 in. – 5 in. (10 cm – 13 cm) thick (concentrated into this thick layer by the action of the boom). The volume of residue was estimated to be 7 bbl (300 gallons), representing 1% – 2% of the original oil volume. Further burning was not conducted because strong winds on the third day of the spill emulsified the oil and spread it over large areas (summarized from Allen, 1990).

Case Study No. 6—Newfoundland Offshore Burn Experiment, Newfoundland, Canada

Case Study No. 6: Newfoundland Offshore Burn Experiment, Newfoundland, Canada

Spill Date: 12 August 1993

Oil Type: Crude oil (API = 36°)

Spilled Volume: Two releases totaling 485 bbls (20,400 gallons)

Burned Volume: All the above

Spilled Volume: Two releases totaling 485 bbls (20,400 gallons)

There were two experimental open-water burns where fresh oil was released into fire-resistant boom and ignited with a Helitorch. The main objective of the experiment was to study air emissions under realistic, full-scale field conditions. About 15% of the oil was turned into smoke (the "smoke yield"). The smoke plume rose rapidly and remained several thousand feet above the surface. All compounds and parameters measured more than about 500 ft (150 m) from the fire were below occupational health exposure levels; very little was detected beyond 1,600 ft (490 m). Pollutants were found to be at lower values in the Newfoundland offshore burn than they were in previous pan tests (summarized from Fingas et al., 1994).

Figure 22. Images from the NOBE Experimental Offshore Burn

Lessons Learned from Prescribed Burning

Information on the ecology and effects of fire on different plant communities is valuable for spill responders considering *in-situ* burning. Dahlin, et al., (1999) provided the following major points, which were derived from Wright and Bailey (1982) and Whelan (1995):

- Soil temperature (in the root zone) influences plant survival more than surface temperature or aboveground temperature;
- Temperature and duration of the burn influence plant impact and survival more than maximum temperature;
- Soil moisture is an important factor during prescribed burns; higher soil moisture protects the vegetation from root damage and also protects organic soils;
- The organic content of the soil is important: inorganic soils are good insulators (2 inches of soil generally protects plant parts from high temperatures); organic soils, especially dry organic soils, can ignite and burn, causing severe impacts to the vegetation and the site;
- Higher fuel load and more flammable fuels cause hotter, more intense and potentially more damaging fires (fuel load refers to live and dead plant material);

- Seasonality is important; many plants are more or less likely to be damaged by fire during different seasons;
- During the dormant season, plants have stored food in their roots which is available for growth immediately after the fire or during the next growing season; thus plant recovery is better during dormant season burns; and
- During the growing season, the food has already been spent so little is left to support regrowth after a fire; thus plant recovery can be poor during growing season burns.

Dahlin, et al., (1999) summarized the fire ecology and effects for over 200 species of plants in habitats that might be considered for *in-situ* burning. They generated tables listing the species name, growth form (e.g., tree, shrub, grass), fire tolerance, whether the species should be considered as a potential type of vegetation for *in-situ* burning, and considerations for use of *in-situ* burning for the species. Responders can use this information to determine how the vegetation at a proposed *in-situ* burn site would respond to fire.

Lessons Learned from ISB on Land

ISB on land can be conducted on a wide range of habitats, from ditches to wetlands. Lessons learned from ISB of spilled oil on land are summarized below (Michel et al., 2002).

- Burning is most effective at reducing damage to vegetation and spreading of the oil to damage additional areas when it is used quickly. Oil is toxic to plants. The vegetation recovery was best when the oil was burned before it had a chance to soak into the soils and affect the roots.
- The window of opportunity for *in-situ* burning to be an effective means of oil removal can be days to months, depending on the spill conditions. Dense vegetation can slow evaporation, extending the window of opportunity for use of *in-situ* burning. For spills with snow and ice cover, burning may still be effective months later. In fact, under snow and ice conditions, it may be necessary to consider additional burns during thaw periods and after the final thaw.
- Light oils (gasoline, aviation fuel, diesel, No. 2 fuel oil, condensate, light crude oils) burn completely, with no residue. Medium and heavy crude oils and heavy refined products form burn residues. If these residues are thick, they have to be removed to speed recovery.

- It is best to have ample water over the soils in vegetated areas to prevent killing the roots by the high heat of the fire and reduce the risk of oil penetration into the soils. At a minimum, the soils in vegetated areas should be water saturated.
- Burning will not reduce the toxic effects of the oil that occurred prior to the burn. It can, however, be very effective at reducing the extent and degree of additional impact by quickly and efficiently removing the remaining oil.
- Responders considering the use of *in-situ* burning should be very aware of the possibility that the fire will spread to unoiled areas. Healthy, green, unoiled vegetation is not always an effective firebreak, particularly downwind and for vegetation that has low moisture content. Fires can quickly jump the kinds of firebreaks placed during spill emergencies in wetlands (e.g., vegetation laid down by the passage of airboats). Responders should consider the consequences of burning adjacent areas in burn plans. Where the spread of the fire is determined to be unacceptable, then additional efforts are needed to control the spread of the fire.

Future Efforts

At the 1998 workshop sponsored by the National Institute of Standards and Technology (NIST) and the U.S. Minerals Management Service (MMS), participants identified and prioritized research and information needs to support decisions on the use of ISB of oil spills. Although most of the focus was for on-water ISB, spills on land were included. Some of the research needs have been addressed already, and there have been significant advances in many areas. Areas still requiring further study are discussed below.

On Land

Oil spill response is a very empirical field; responders learn what to do and not to do by experience. Without documentation, they cannot learn from past spills. There are relatively few well-documented cases of using ISB on land, although it has been used often. Therefore, it is very important to record observations on the site conditions prior to burns on land (oiled area, oil thickness, amount of water on the surface, soil and vegetation type) and post-burn (duration of the burn, amount of oil remaining, amount of water remaining, soil conditions, area burned). These observations will allow objective evaluation of the effectiveness and effects of the burn, to help identify the conditions when ISB should and should not be used in the future. With this knowledge, more specific guidelines can be developed for the proper use of ISB for different habitats (e.g., tundra, marsh, shoreline, lakes).

Where possible, a part of the oiled area should be isolated from the burn so that the relative rates of recovery can be compared. To-date, there are no studies of field burns where part of the oiled area was burned and part remained unburned. The main reason is because it is hard to protect an oiled area from burning. Use of ISB is often a trade-off between the impacts of the burn and the impacts of no further cleanup, or the impacts of aggressive cleanup. It would be useful to have more information on which to make such decisions.

ISB sites should be monitored to learn the actual recovery rates of the impacted habitat. We have learned much from past burns, and we have a better understanding of when ISB is likely to be the preferred response option, but more studies will improve our knowledge base. Simple monitoring plans should be developed as part of the pre-planning for use of ISB. The study designs could consist of several tiers of data collection, from time-series photographs of study plots, to field measurements of species abundance and diversity, to chemical analysis of sediments to track the rate of oil weathering. Implementation of these kinds of monitoring studies could be required as part of the approval process, particularly for habitats or conditions that are unusual.

On Water

ISB of oil on open water has been used at one spill (Exxon Valdez) in the U.S., although there have been other spills where it could have been used in a safe and efficient manner. The public perception is that there are not many situations where ISB is practical. Therefore, a practicality study using realistic spill scenarios and response capabilities is needed to identify those conditions where burning could be a feasible response option.

Better techniques are needed for using ISB nearshore and along the shoreline on rivers. ISB could be used for spills on rivers in remote areas or sites with poor access where equipment cannot be deployed. However, techniques needed to be devised and tested for diverting oil from the fast-flowing areas to sites where it can be contained and burned. Right now, there is no fire-resistant river boom. Further work is needed on all kinds of fire-resistant booms, to improve their performance and ease of deployment.

There is a need for better techniques to ignite the oil using hand-held igniters. The Helitorch is good for aerial ignition and where there is a need for starting fires in lots of places on the oil. Hand-held igniters are appropriate for many conditions. But, hand-held igniters need improvements, such as higher reliability and the option for a delay (no flames or sparks) while in the user's hands and after activation.

Techniques for controlling and extinguishing an on-water burn need better refinement. The commonly proposed method of releasing the boom and allowing the oil to spread to the point where the fire goes out has not actually been done. The use of fire-fighting foam has not been explored.

List of Acronyms

ACS .... Alaska Clean Seas
API .... American Petroleum Institute
ASTM .... American Society for Testing and Materials
bbl .... Barrel
BTEX .... Benzene, Toluene, Ethyl Benzene and Xylenes
cm .... Centimeter
CO .... Carbon Monoxide
CU .... Copper
DOI .... Department of Interior
DRO .... Diesel Range Organics
EPA or USEPA .... U.S. Environmental Protection Agency
ESA .... Endangered Species Act
FE .... iron
FEIS .... Fire Effects Information System
FOSC .... Federal On-scene Coordinator
ft .... Feet
HAZWOPER .... Hazardous Waste Operations and Emergency Response Standard
IC .... Incident Commander
ICS .... Incident Command System
ISB .... *In-situ* Burn(ing)
MOA .... Memorandum of Agreement
mm .... Millimeter
NAAQS .... National Ambient Air Quality Standards
NI .... Nickel
NIST .... National Institute for Standards and Technology
NOAA .... National Oceanic and Atmospheric Administration
NOBE .... Newfoundland Offshore Burn Experiment
NOx .... Nitrogen Oxide
NRC .... National Research Council
NRT .... National Response Team

OSC..On-scene Coordinator
OSHA...Occupational Safety and Health Administration
PAH ....Polycyclic Aromatic Hydrocarbons
PM-2.5 ....Particulate Matter, 2.5 Micrometer Size or Smaller
PM-10 ....Particulate Matter, 10 Micrometer size or smaller
ppm ....Parts per Million
RRT...Regional Response Team
SMART.. Special Monitoring of Applied Response Technologies
SO2 ....Sulfur Dioxide
TPH.. Total Petroleum Hydrocarbons
TWA ....Time Weighted Average
UC .... Unified Command
USCG...U.S. Coast Guard
VOC.. volatile organic compounds

Generic ISB Checklist for Oil Spill Response

The following checklist provides a general summary of important information to be considered by the Unified Command, consisting of the federal On-scene Coordinator (FOSC), state On-scene Coordinator (SOSC), and responsible party representative (RP) when planning for the use of *in-situ* burning in response to an oil spill in marine waters. This and other similar documents are intended to allow Unified Command verification of a decision, rather than an information distribution sheet or an approval form. ***Check with the region-specific regional contingency plan to determine if a specific checklist is required in the waters being considered for an ISB.***

Each section of the checklist provides a series of "limiting factors" questions. Some sections also contain a "worksheet" for important information that may be necessary to answer limiting factor questions; the user is encouraged to attach forms that already contain this information if they are readily available.

Questions in the limiting factors section that are answered with a "Yes/Optimal" support the decision to conduct an *in-situ* burn. However, spill response involves numerous tradeoffs, and any less-than-ideal conditions that are represented by a "No/Sub-optimal" answer may be balanced by other benefits of *in-situ* burning in a given situation. Not every question of the worksheet must be answered. It is acceptable for the Unified Command to make a decision based on incomplete information, provided the information gaps are understood and considered.

In-situ Burn Decision:

☐ Federal On-scene Coordinator Decision: ___ Approve Signature: ______________________

☐ State On-scene Coordinator Decision: ___ Concur Signature: _________________________

☐ Responsible Party Decision: ___ Concur Signature: __________________________________

Verify if additional consultation or concurrence is required in Zone C (or Zone B if winds are not from the pre-approved directions) for your region.

Agency/Contact Concurrence/consultation Time/Date Method (verbal, written): _____________

____

____

____

Points of Contact for Checklist: *(Name/Position/Telephone)*

☐ Federal: ____

☐ State: ____

☐ Responsible Party: ____

☐ Scientific Team: ____

☐ Other: ____

☐ Other: ____

☐ Other: ____

Incident Information *(To be Completed by Requesting Party)*

☐ Incident Name: ____

☐ Current date/time: ____

☐ Anticipated burn date/time: ____

☐ Location of spill (descriptive): ____

☐ Location of burn (descriptive): ____

Spill Location/Trajectory *(To be Completed by Scientific Support Team)*

☐ Trajectory (Graphic Attached) ___ Yes ___ No -or- Text: ______________________

☐ Overflight Map (Graphic Attached) ___ Yes ___ No -or- Text: ______________________

To be Completed by OSC Representative:

☐ Consultations/Concurrence based on location of approval area of burn : ___Yes; __No; Comments: ____

- Zone A; More than 6 miles offshore: FOSC approval of burn? ______________________
- Zone B; 3 – 6 miles offshore with decidedly offshore wind: FOSC approval of burn? ______ ____
- Zone C; Less than 3 miles offshore: FOSC approval of burn? ______________________

☐ EPA RRT co-chair concurs with burn? ______________________________

☐ State(s) RRT representative concurs with burn? ______________________________

☐ Consultation with DOI RRT representative? ______________________________

☐ Consultation with NOAA RRT representative? ______________________________

☐ Other Region consultation/concurrence if burn to impact neighboring Region? ___________

☐ Notifications planned as described in MOU (EPA, DOI, NOAA, State(s)? _______________

☐ Attachments/Additional Information: ______________________________

To be Completed by Scientific Support Team: *(Optimal/Sub-Optimal)*

☐ Oil Burnability: ___Yes; ___Probable: __No; ___Unlikely; Comments: ________________

☐ Anticipate oil to remain ignitable (fresh, not highly emulsified)?: ______________________

☐ Attachments/Additional Information: ____

To be Completed by Scientific Support Team: *(Optimal/Sub-Optimal)*

☐ Weather/Sea Conditions: ___Yes; ___Probable; __No; ___Unlikely; Comments: _______

☐ Weather forecast precipitation-free (affects ignition)?: ______________________________

☐ Winds/forecast winds less than 25 knots? ____

☐ Visibility sufficient for burn operations/observations (greater than 500 feet vertical, 1/2 mile horizontal)? ____

☐ Wave heights/predicted wave heights less than 2 – 3 ft? ___________________________

☐ Attachments/Additional Information: ____

To be Completed by Requesting Party: *(Optimal/Sub-optimal)*

☐ Operational feasibility : ___Yes; ___Probable; ___No; ___Unlikely; Comments: ________

☐ Is an operational plan written or in process? (if available, attach) ______________________

☐ Is needed air support available? ____

☐ Are personnel properly trained, equipped with safety gear, and covered by a site safety plan?

☐ Are all necessary communications possible (i.e. between aircraft, vessels, and control base in an open water burn)? ____

☐ Can all necessary equipment be mobilized during window of opportunity (i.e., fire boom, igniter, tow boats, residue collection equipment)? ___________________________________

☐ Can undesirable secondary fires be avoided? ______________________________________

☐ Can burn be safely extinguished or controlled? _____________________________________

☐ Can aircraft pilots and mariners be adequately notified, as necessary? ___________________

☐ Is equipment and personnel available for residue recovery? _________________________

☐ If ignition from a helicopter, FAA approved equipment? ______________________________

☐ Attachments/Additional Information: ____

To be Completed by OSC/SOSC Staff in Consultation with Meteorologists/ Modelers as Appropriate: *(Optimal Condition/Sub-Optimal Condition)*

☐ Human and Environmental Impacts: : ___Yes; ___Probable; ___No; ___Unlikely; Comments: ____

☐ Public exposure to PM-10 (particulates <10μm) not expected to exceed 150 μg/m3 averaged over 1 hour as a result of burn? (current NRT planning guideline): ___Yes; ___Probable; ___No; ___Unlikely; Comments: ___________________________________

☐ Can burning be conduced at a safe distance from other response operations, and public, recreational and commercial activities? ____

☐ Is particulate (hour-averaged PM-10) monitoring available? _________________________

☐ Can public be adequately notified of burn? ______________________________________

☐ Trustees consulted if endangered species in immediate burn area? ____________________

☐ Attachments/Additional Information: ____

Public Health/Plume Worksheet *(Open Water and Inshore):*

☐ Distance/direction to nearest population relative to burn: _____miles to the _____(direction)

☐ Distance/direction to nearest downwind population: _____miles to the _____(direction)

☐ Forecast wind speed/direction (24 hour): _____mph from the ______(direction)

☐ Forecast wind speed/direction (48 hour): _____mph from the ______(direction)

Estimated plume trajectory (text or attached graphic): __________________________________

Other comments/issues: ____
____
____

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