

APPENDIX VI: IN SITU BURNING OF OIL AS A RESPONSE TOOL IN REGION 5

Guidance for Approving Proposals to Burn Oil

Prepared for Region 5 Regional Response Team by Countermeasures Workgroup, Region 5
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Part I

INTRODUCTION

In order to minimize the environmental impacts and facilitate effective cleanup of an oil spill, responders have a limited number of techniques available to them. These include:

- mechanical methods,
- the use of certain chemical countermeasures, and
- in situ burning

Under certain specific conditions, in situ burning may offer a logistically simple, rapid, inexpensive, and relatively safe means for reducing the shoreline impacts of an oil spill. Moreover, because a large portion of the oil is converted to gaseous combustion products, the need for collection, storage, transport, and disposal of recovered material can be substantially reduced.

In situ burning may be able to remove large amounts of spilled oil before spreading and drifting of the spill fouls shorelines and threatens wildlife. In certain circumstances, such as oil spilled in ice conditions, burning may be the only viable response technique. For these and other reasons, in situ burning is gaining attention and favor as a potential oil spill response technique.

In situ burning must be evaluated in conjunction with other containment and cleanup alternatives. Specific spill conditions will often dictate the response techniques used and selection always involves tradeoffs. For example, a potentially ecologically damaging but efficient cleanup technique could be used to meet site-specific response goals. Also, techniques may be used early in response simply because they can be implemented immediately, rather than waiting until ones with lower impact can be mobilized. In situ burning, which might have a significant short-term impact, may actually produce the lowest long-term impact because it removes the oil quickly.

This policy document contains the background information and guidance necessary to aid the Federal and State OSC, the appropriate RRT members, and Area Committees in their consideration of whether to allow the use of in situ burning as an oil spill countermeasure.

1. RRT 5 POLICY FOR USING IN SITU BURNING AS AN OIL SPILL RESPONSE TOOL

RRT5 strongly recommends that in situ oil burning be considered as a means to avert potential oil spill impacts to the region's beaches, wetland environments, and Great Lakes and inland resources. In situ burning should augment, not replace, other oil spill response techniques such as mechanical removal or chemical countermeasures. Where and when appropriate, in situ burning can be used as a first-strike option for defensive purposes (e.g., open water burning and burning in ice conditions), and as a cleanup technique (e.g., burning of wetlands to remove spilled oil).

Since the use of in situ burning is being encouraged, education of the public and the response community is also necessary to reduce misconceptions and anxieties. This should be accomplished by outreach to public forums and in the area planning/committee process.

The RRT has adopted this policy applicable to spill responses under the direct oversight of a Federal On-Scene Coordinator (FOSC). This policy authorizes the FOSC to use in situ burning as a response countermeasure to an oil discharge when he or she believes it is appropriate after key members of the RRT have been consulted and concur. In some circumstances this policy is overridden by State laws and in the case of the use of burning agents during in situ burning by the NCP (40 CFR 300.910). To the extent that this policy applies, the following summarizes the appropriate situations where concurrence and consultation should take place:

- a) The requirements of this policy apply only to responses under the direct oversight of an FOSC, but its general application is strongly encouraged.
- b) The appropriate State's approval is always required. In Region 5, the use of in situ burning as a response tool will always be within State waters and inland areas and consequently be subject to State law and policy. When burning agents are used this is a requirement of the law (the NCP).
- c) The U.S. Environmental Protection Agency (U.S. EPA) must concur with the Federal OSC's recommendation to authorize the use of in situ burning. When burning agents are used this is a requirement of the law (the NCP).
- d) The U.S. Department of Interior (DOI) must also concur with the decision to burn during a spill response overseen by a Federal OSC. The responsibility of concurrence is given to DOI because of its authorities, and potential assistance to the Federal OSC, regarding the Endangered Species Act and potential representation of Federally recognized Native American communities. Furthermore, DOI has significant responsibilities as a Federal natural resource trustee.
- e) As a natural resource trustee, the Department of Commerce (DOC/National Oceanic and Atmospheric Administration (NOAA) should be consulted when considering an in situ burn. Notification should be from the RRT Co-Chairs via the DOC RRT member.
- f) Native American community official(s) must be consulted on any decision to use in situ burning when a burn would reasonably be expected to impact those designated areas of Native American interests.

- g) Finally, this approval must also be in concert with Canadian Federal Government officials, adjoining States and/or provinces, and local officials with approving jurisdictions, where deemed appropriate or necessary. Additionally, the NOAA Scientific Support Coordinator (SSC) should be contacted to assist in the decision-making process.

The use of in situ burning for response will follow the Region 5 approved guidelines and procedures established to allow the State and Federal On-Scene Coordinator the safe and effective use of this response tool. This includes, but is not limited to, the RRT 5 Cleanup Guidelines.

***Special Note on Notification:** Once notified by the RRT Co-Chairs, DOI must develop its position on the burn in a limited timeframe consistent with the incident-specific conditions and response limitations. Typically this would be on the order of hours. Significant efforts will be made to contact DOI; however, if no contact can be made within a reasonable timeframe, a decision to burn will be made without DOI concurrence. The Co-Chairs will establish this incident-specific time frame and provide DOI with the spill information and Federal OSC justification for conducting the burn.*

1.1. Authority

Section 300.115 of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) states that the RRT is responsible for regional planning and coordinating preparedness and response actions. The NCP further states, "...[The RRT] provides the appropriate regional mechanism for development and coordination of preparedness activities before a response action is taken and for coordination and advice to the OSC/RPM during such response actions...."

Section 4201 of the Oil Pollution Act (OPA; P.L. 101-380) amended the Clean Water Act, which gives the general removal authority to "...ensure effective and immediate removal of a discharge, and mitigation ...of oil..." This same section requires the contents of the NCP to contain "...procedures and techniques to be employed in identifying, containing, dispersing, and removing oil...."

Finally Section 7001 of OPA supports the concept of developing innovative technologies that are effective "...in preventing or mitigating oil discharges and which protect the environment...."

2. IN SITU BURNING AS A RESPONSE TOOL—AN OVERVIEW

2.1. Definition

In situ burning, for the purposes of this guidance, is defined as the use of an ignition source to initiate the combustion of spilled oil that will burn due to its intrinsic properties and does not include the adding of a burning agent to sustain the burn.

The use of in situ burning in these guidelines is not for disposal purposes; rather, it is a response technique to be employed when an oil slick is virtually uncontrolled with the potential to spread

and contaminate additional areas. It is also considered as a cleanup technique for oiled shoreline habitats such as wetlands, where it is used in conjunction with other cleanup methods.

2.2. Potential Effectiveness

Although in situ burning is a relatively simple technique, its effectiveness can be limited by spill circumstances. Whether and how oil burns is the result of the interplay among a number of physical factors related to the oil itself and the extent to which the oil has been exposed to the environment. Critical factors, including:

- oil thickness,
- degree of weathering, and
- extent of emulsification

generally change with the passage of time, and the changes that occur make it more difficult to burn the oil. As a consequence, in situ burning is most easily and effectively implemented during the early stages of a spill.

The efficiency of in situ burning is highly dependent on a number of physical factors. Test burns and actual spill situations suggest it can be very effective in removing large quantities of oil from the water. Burn efficiencies of 50 to 90 percent can be expected, making this response method more efficient than other methods. In comparison, mechanical removal (such as skimming) typically has an efficiency of 10 to 20 percent.

In situ burning is most considered and tested with crude oil spills. However, its feasibility with other types of refined oil products (e.g., diesel and Bunker C fuel oil) has been demonstrated. Difficulties with establishing and maintaining necessary slick thicknesses (in the case of lighter oils) and ignition (for heavier oils) make in situ combustion a slightly less viable alternative for those materials than for crude oils.

*An additional source of information about applicable habitats in which to conduct in situ burning is the joint NOAA/American Petroleum Institute document, **Options for Minimizing Environmental Impacts of Freshwater Spill Response**.*

2.3. Relationship to Mechanical and Other Response Methods

Spill prevention is the first line of defense in spill response planning; however, acceptance of the probability that a spill can and will occur is essential to successful preparedness. Burning will be considered as a possible response only when mechanical containment and recovery response methods are incapable of controlling the spill alone.

While physical containment and mechanical removal of spilled oil is the primary objective of any response, prudent planning dictates the consideration of alternative countermeasures.

2.4. Byproducts of In Situ Burning

Byproducts of in situ burning exist because no combustion is completely efficient in oxidizing a given source material. Besides the normal results of burning, CO₂, H₂O, and an assortment of other sulfur and nitrogen residues, a wide range of intermediate combustion products are generated. Although the exact mix of burn residues varies, byproducts can be categorized into three groups: unburned oil, airborne components, and combustion residues. Each of these is discussed in greater detail in Part II of this guidance document.

3. SAFETY AND HUMAN HEALTH CONSIDERATIONS OF IN SITU BURNING

3.1. Safety of Response Personnel

The safety of personnel during both ignition and burn phases of large amounts of combustible liquids on the surface of the water presents some unique safety concerns for workers and response personnel. Many of these concerns are addressed in greater detail in operationally oriented references and include, but are not limited to, the following:

- a) **Fire Hazard:** Care must be taken that the burn be controlled at all times to ensure the safety of personnel and property. This precludes burning sources such as tankers, ships, or tank farms unless means are taken to ensure that the flame cannot propagate from the burn location to the source.
- b) **Ignition Hazard:** Personnel and equipment involved in ignition of the oil slick must be well coordinated. Weather and sea conditions need to be kept in mind and adequate safety distances be kept at all times. Specialized ignition equipment, unknown fire behavior, and uncertain flash points introduce safety risks.
- c) **Vessel Safety:** Burning at sea may involve the use of several vessels operating in close proximity, perhaps at night or in conditions of poor visibility. These conditions are hazardous by nature and generally require training and close coordination. Maneuverability while towing boom or positioning other containment equipment will require skilled personnel.
- d) **Training:** Training of personnel to operate equipment for in situ burning should be developed to minimize the risk of injury and accident. Training should meet all applicable OSHA regulations and guidelines.

Response personnel working in close proximity to the burn may be exposed to levels of gases and particulates that may require the use of personal protective equipment. Training for burn personnel should include proper use of personal protective equipment that may be used to minimize inhalation of and skin contact with combustion byproducts. Exposure limits such as OSHA's Permissible Exposure Limits (PELs) are applicable to this group of typically healthy adults.

Other hazards can include the exposure of personnel to extreme heat conditions, smoke, and fumes. Work also may be done under time constraints or for extended periods of time. Personnel involved with burning operations must be well briefed on the plan of operations, with safety stressed, and must be notified of all changes from the approved burn plan. The need for burning must be constantly evaluated and should be reconsidered if conditions (e.g., weather, operations, equipment) pose a threat or danger to human health and safety, or facilities. As more knowledge is gained from burning, it is most likely that additional safety concerns will be identified.

3.2. General Public Health Considerations

Burning oil produces a visible smoke plume containing smoke particulates, combustion gases, unburned hydrocarbons, residue left at the burn site, and other products of combustion. It also results in the evaporation and release of volatile compounds from the oil. Public health concerns relate to the chemical content of the smoke plume and the downwind deposition of particulates. It should be noted that not burning an oil spill also introduces its own air quality concerns. Analysis of the physical behavior of spilled oil has shown that 50 percent of a light crude oil spill can evaporate fairly readily, and it is the acutely toxic lighter fractions of a crude oil mix that quickly move into the atmosphere.

Results of recent burn tests indicate that in situ burning does not yield significant emissions above those expected for similar types of combustion such as forest fires. Many human health experts believe that the most significant human health risk resulting from in situ burning is inhalation of the fine particulate material that is a major constituent of the smoke produced. An early assessment of health concerns attributable to the Kuwaiti oil fires identified the less than 10-micron particulate matter as representing the greatest health hazard in that situation. The extent to which these particles present a health risk during an in situ burn depends on the concentration and duration of the exposure. It is important to remember that particulates in these concentrations are so small that they do not settle readily. They will be carried by the prevailing wind over large distances, over which their concentrations will rapidly decline.

Polynuclear aromatic hydrocarbons (PAHs) are a group of hydrocarbons produced during in situ burning. They are found in oil and oil smoke, where their relative concentration in the latter tend to be higher than in the oil itself. Possible carcinogenicity of some members make this group a serious health concern, although it is generally long-term exposure to the higher molecular-weight PAHs that is the basis for concern. Sulfur dioxide (SO₂) and nitrogen dioxide (NO₂) are eye and respiratory tract irritants that are produced by oil combustion. Concentrations of PAHs decline downwind as smoke from the fire is diluted by clean air. The concentrations of other byproducts of burning oil (i.e., combustible gases) also decline downwind.

Burning should not be allowed if downwind human populations are at risk. The downwind extent of human risk has not been empirically determined, although it is an area of very active research. There are no exposure standards for respirable particles generated by a burn that could be applied directly to determine safe downwind distances. Atmospheric dispersion models, if available for the specific area, could be utilized to help refine potential downwind exposures. If models are not available, whenever possible, a small pilot burn could be conducted before a larger burn in order to gauge the effectiveness of the ambient conditions to disperse the smoke and gases

resultant from the burned material. Because wind direction meanders under most circumstances, no population should be within a 45-degree arc to either side of the wind direction. Local wind and weather events (air stability class, lake breezes, and frontal passages, for example) must be considered when determining downwind directions.

3.3. Public Notification

Notification of the public of an impending burn is critical to the overall success of an in situ burn effort. The notification, coordinated through the joint information center, should focus on conveying the following messages:

- Burning is a simple, well-understood, and controlled practice;
- Strict health and environmental criteria are being used in deciding whether or not to burn;
- Burning is being conducted because it presents the opportunity for greater health and environmental protection than could be achieved by other spill response methods or no response;
- Health and environmental precautions will accompany burning;
- The burns will be carried out by specially trained personnel and will be closely monitored;
- The public will be notified of each burn before or as it begins.

Public notification can be initiated through radio/TV broadcasts and broadcasts to mariners. If necessary, local government and State emergency service personnel with access to established public warning systems and authority to use them can facilitate this notification.

Materials to educate the public and media about burning, its risks, and tradeoffs with other countermeasures, should be developed ahead of time and available for dissemination during the burn. This material would cover the tradeoffs involved in choosing response countermeasures, and relate the risks of in situ burning to better known risks (e.g., forest fires). Distribution of this information can be through the agencies' public affairs offices prior to a spill and through a joint information center established during a spill.

Additional information about effectiveness can be found in Part II - Technical and Background Information.

4. ECOLOGICAL CONSIDERATIONS OF IN SITU BURNING

4.1. Open Water In Situ Burning

Potential ecological impacts of open water in situ burning have not been extensively discussed or studied. Conclusions are based on documented physical effects observed in the laboratory and at limited test burns. The surface area affected by in situ burning is likely to be small relative to the total surface area and depth of a given body of water. This does not necessarily preclude adverse

ecological impacts, particularly if rare or sensitive species use the waters in question. Organisms that may be affected by in situ burning include those that use the uppermost layers of the water column, those that might come into contact with residual material, and possibly some benthic (bottom-dwelling) plants and animals. ***Additional information about worker and general public health and safety can be found in Part II - Technical and Background Information.***

4.2. Direct Temperature Effects

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

4.3. Surface Microlayer

4.3.1. ROLE AND IMPORTANCE OF THE SURFACE MICROLAYER

The surface of the water represents a unique ecological niche called the "surface microlayer," which has been the subject of many recent biological and chemical studies. Although most studies of the microlayer have been conducted in the marine environment, the results can also be applied to the freshwater environment. The microlayer, variously defined but often considered to be the upper millimeter or less of the water surface, is a habitat for many sensitive life stages of aquatic organisms, including eggs and larval stages of fish and crustaceans, and reproductive stages of other plants and animals. The microlayer also is a substrate for microorganisms and, as such, is often an area of elevated microbial population levels and metabolic activity.

4.3.2. POTENTIAL EFFECTS OF BURNING ON THE SURFACE MICROLAYER

The ecological importance of the surface microlayer and the potential impacts to it from burning activities have been discussed in the different, but related, context of ocean incineration. The Office of Technology Assessment (1986) noted in an evaluation of the technique:

"... given the intermittent nature of ocean incineration, the relatively small size of the affected area, and the high renewal rate of the surface microlayer resulting from new growth and replenishment from adjacent areas, the long-term net loss of biomass would probably be small or non-existent."

Despite the obvious differences between shipboard incineration of hazardous wastes and surface burning of spilled oil, the above rationale is applicable to in situ burning. Accordingly, potential impacts to the ecologically important surface microlayer are, to some extent, offset by the presumably short-lived nature of the burn and its associated residual material.

4.4. In Situ Burning in Wetland Habitats

There are few studies on the relative effects of burning oiled wetlands compared to other techniques or natural recovery and most of the experience is derived from estuarine habitats. However, in situ burning in wetlands can be effective since it can remove a large quantity of oil with a minimum of physical disturbance. The type of wetland vegetation and the season of the year, along with many other factors, will dictate whether burning is feasible in a particular wetland.

Refuge managers have historically conducted prescribed burns of wetlands to:

- rejuvenate wetlands that have accumulated high litter loads,
- generate green vegetation or open spaces to attract wildlife,
- release nutrients for recycling, and
- restore habitats in areas that were historically subject to frequent wildfires to their natural conditions.

The presence of oil in a wetland may have two important effects:

- a) the high Btu of the oil may increase the temperature and heat penetration of the burn, and
- b) there is often an oil residue which can cause toxicity.

However, the experiences of fire ecologists and practitioners can greatly contribute to the development of guidelines for burning wetlands as a spill response strategy. Guidance is being developed for specific types of wetlands such as:

- wooded swamps
- fresh-to-brackish impoundment marshes
- Great Lakes coastal marshes
- Upper Mississippi River marshes (lock and dam pools)
- riparian wetlands
- inland freshwater marshes
- potholes

For now, based on discussions with refuge staff with fire management duties, the following general considerations for use were developed:

(a) Pros

- Where access is limited or mechanical/manual removal has the potential to cause more damage by equipment and trampling, burning can rapidly remove oil from sensitive areas.
- It provides a response option when no others are acceptable, or where likely oil residues will be unacceptably high with other options, including natural recovery.
- It rapidly removes oil from the habitat when there is a time-critical element, such as a short-term change in the physical conditions which will likely cause loss of containment and further spreading, or a seasonal increase in wildlife use, such as arrival of large numbers of migratory waterfowl.

(b) Cons

- Burning can cause substantial initial plant damage because the aboveground vegetation is removed.
- Burning can cause long-term impacts to vegetation, especially if the fire is so hot that the below-ground plant parts are killed.
- There is a potential for burning to increase oil penetration into the substrate, when there is no standing water. · Any animals present and unable to escape (such as gastropods on clean vegetation above the oiled area) will be killed. ***Part II of this document contains summary of published case studies where the burning of marshes was used as a response tool.***

4.5. Environmental Toxicological Considerations

Although many studies to define the physical and chemical characteristics that result from in situ burning have been performed, there has been little research on potential ecological effects. To address some of these information shortfalls, Environment Canada coordinated a series of studies to determine if in situ burning resulted in water column toxicity beyond that attributable to allowing the slick to remain on the surface of the water. While these studies centered on the Newfoundland in situ burn field trials conducted in August 1993, they also included laboratory tests to investigate potential effects in a more controlled environment.

Toxic effects were evaluated using three standard marine test organisms: sand dollar, oyster, and fish. In both the laboratory and the field experiments, sensitive toxic endpoints in these organisms were studied in the three situations of no oil, no burning; oil on water, no burning; and oil on water, burned. Results from the laboratory and field studies indicated that although toxicity increased in water samples collected below burning oil on water, this increase was generally no greater than that caused by the presence of an unburned slick on water. Chemical analyses performed in conjunction with the biological tests reflected low hydrocarbon levels in

the water samples. In addition to water column samples, the residues remaining after the laboratory and Newfoundland field burns will be subjected to aquatic toxicity testing.

Beyond the direct impacts caused by high temperatures, the byproducts of in situ burning may be toxicologically significant. Although analysis of water samples collected from the upper 20 cm of the water column immediately following a burn of crude oil yielded relatively low concentrations of total petroleum hydrocarbons (1.5 ppm), compounds that have low water solubility or that associate with floatable particulate material tend to concentrate at the air-water interface (U.S. EPA 1986). Strand and Andren (1980) noted that aromatic hydrocarbons in aerosols originate from combustion associated with human activities, and that these compounds accumulate in the surface microlayer until absorption and sedimentation remove them.

Burn residues could be ingested by fish, birds, mammals, and other organisms, and may also be a source for fouling of gills, feathers, and fur. However, these impacts would be expected to be much less severe than those manifested through exposure to a large, uncontained oil spill. Contamination is likely to be local in scale, affecting certain unique populations and organisms that use surface layers of the water column at certain times to spawn or feed. In crafting an effective and protective response strategy, these effects should be weighed against effects resulting from alternative actions.

5. OPERATIONAL CONSIDERATIONS FOR CONDUCTING IN SITU BURNING

5.1. Open Water Burning

An open water in situ burning technique most likely to be used would involve the use of boats towing fire-resistant booms that could be used to contain the spilled oil and keep it from spreading. The boom, attached to the boats by towing lines, would be towed such that it forms a "U" shape. The open end of the U is maneuvered through the oil slick, and a "boomfull" of oil is collected. The boom is towed away from the main slick and the oil is ignited. During the burning, the boom is pulled in such a way as to slowly advance ahead to ensure that the oil is concentrated at the back end of the boom and to maintain maximum thickness. A burn can be terminated by letting the oil layer thin out by releasing one end of the boom. After the oil is consumed, the process is repeated. Other techniques may include containing the oil continuously spilling from a burning oil rig, or placing fire boom around a tanker that caught fire.

5.2. Burning in Other Inland Environments

Although it is widely held that in situ burning does take place in the inland zone, little technical information exists on techniques and impacts of burning in environments other than open water. In most cases, these involve burning in ice conditions and in wetlands and the results are varied and anecdotal.

5.2.1. IN SITU BURNING IN ICE/WINTER CONDITIONS

Containment is almost always required to maintain the minimum 2- to 3-cm thickness necessary to burn oil. Ice edges can act as natural barriers, and as long as the oil is of sufficient thickness,

combustion is possible. However, wind and/or low currents may be necessary to herd the oil into sufficient thickness along the edge. Oil trapped under the ice may also accumulate in sufficient thicknesses along leads in broken ice, resulting in favorable conditions for burning. Test burns in a 1986 Esso wave basin showed burning efficiencies of up to 90% where moderate winds herded the oil into long narrow leads. Burning in other lead geometries and along brash ice resulted in less efficient burns. Arctic studies have also shown that it is possible to ignite and burn fresh, weathered, and emulsified oil at temperatures as low as -35 degrees Celsius. It is important to note that an in situ burn in broken ice is not easily extinguished once ignited.

Burning oil in snow conditions is similar to burning oil on water since as the snow melts during the burn it can form a meltwater pool upon which the oil continues to burn. Certain conditions such as wind, snow properties, and concentration of the oil in the snow all can impact the success of the burn. Burn efficiencies of 90 to 99 percent have been shown during field studies and actual spills. Oil/snow mixtures of up to 75 percent can be ignited with a diesel or gasoline-soaked rag (from *Detection of Oil in Ice and Burning Oil Spills in Winter Conditions*, PROSCARAC, Inc., March 1992).

5.2.2. IN SITU BURNING IN WETLANDS AND MARSHES

Based on very limited data on effectiveness and effects of burning on oiled marshes, the following guidelines are suggested:

- a) Make sure that it is possible to contain and control the fire; it is not as easy to put out a fire in vegetation as it is with oil contained in a fireproof boom.
- b) Impacts to below-ground vegetation are likely to be lower if there is a water layer between the oil and the substrate.
- c) A standing water layer of just a few inches may get hot enough to kill the roots anyway; however, little information is available regarding this effect.
- d) Burning of oiled woody wetland vegetation (compared to grasses and sedges) should not be considered.
- e) Not enough is known about seasonal effects on the ability of burned, oiled vegetation to recover, yet burning in late fall to early spring, when the vegetation is dormant and before production of new growth, seems to be the best time.
- f) If it can be done with minimal impacts, heavy accumulations of oil should be removed using other methods, to reduce the amount of burn residues, which may cause long-term impacts to both vegetation and animals returning to the habitat.
- g) Light fuels oils and crudes burn more efficiently and generate less residues, which should reduce the potential for long-term impacts.

- h) Burning of oil trapped in ice appears to have the least environmental impact because the burn area is contained, the plants are dormant, and the above-ground vegetation is dead.
- i) There is some concern that burning of muddy substrate could alter their physical properties (i.e., make them hard), thus degrading their biological productivity.
- j) Every wetland is different in terms of the type of wetland, the species growing there, the condition (optimal or marginal for species use), and the known or estimated tolerances of that type of system to physical and chemical disturbances. Biologists or botanists should be consulted prior to the use of burning as a cleanup technique in a wetland.

5.3. Fire Resistant Boom

The application of in situ burning requires the physical collection and containment of oil to maximize the efficiency of the burning process and to provide a means to control the burn. Generally, this is accomplished by the use of a fire boom or some type of fire resistant containment. If fire boom or other fire containment device is not available and/or the equipment to deploy the boom is unavailable or inadequate, approval for use of in situ burning may be denied.

5.4. Ignition

Heavy oils require longer heating times and a hotter flame to ignite compared to lighter oils. Many ignition sources can supply sufficient heat. These include pyrotechnic igniters, laser ignition systems, and aerial ignition systems. Pyrotechnic devices have been successfully used to ignite floating oil slicks under a range of environmental conditions. Disadvantages to their use are associated with safety, shelf life, availability, speed of deployment, and cost (Spiltec, 1987). Laser ignition, while a promising technique, remains experimental in nature with drawbacks associated with difficulties in beam focusing from the air, wind effects during oil preheating, energy requirements, and cost. Aerial ignition systems using gelled gasoline dropped from helicopters appear to be a more viable technique applicable in a range of environmental conditions. Whichever method is used, considerations of safety and efficiency must enter into the decision process.

5.5. Oil Thickness

In general, oil slicks can be effectively burned if they are consistently 2 to 3 mm thick. This number can vary with oil viscosity and degree of weathering with more viscous and more weathered oils requiring a considerably thicker layer of oil (estimated to be nearly 10 mm). Also, burn efficiencies increase as thickness of the slick increases. This consideration, therefore, implies that spilled oil must be contained by some means (fire resistant boom, ice, etc.) in order to prevent oil spreading and the resultant thinning of surface layers. ***Further information on the efficacy of fire-resistant booms can be found in Part II - Technical and Background Information.***

5.6. Effects of Weathering

Weathered oil requires a longer ignition time and higher ignition temperatures. However, igniting weathered oil is generally not a problem with most ignition sources because they have sufficient temperature and burn time to ignite most oils. Weathering, as it affects the ability to burn oil, is currently under study in laboratory and field experiments.

5.7. Effects of Emulsification

The effect of water content on oil ignition is believed to be similar to that of weathering, in that it decreases ignitability and combustibility. However, oil containing some water can be ignited and burned. The controlling factor in the combustion of emulsions is the removal of water, which is accomplished either through the boiling of the water out of the emulsion, or by breaking the emulsion thermally or chemically. The effect of emulsions on the ability to burn oil is currently under study in laboratory and field experiments.

5.8. Unburned Oil and Solid Burn Residues

Although in situ burning has the potential for removing a large proportion of the mass of an oil spill from the water surface, some of the source material will not be consumed and will remain as a concern. Similarly, combustion residues, described as stiff, taffy-like material, will remain after the burn. Provisions for the removal of these materials must be made as the potential exists for undefined levels of shoreline impacts even with a successful burn.

Although sinking of burn residues has seldom been observed in test burns, a slight increase in density relative to the original oil has been observed. In the 1991 explosion and burning of the tanker *Haven* off Genoa, Italy, burn residues were thought to have sunk. Reliable estimates of the amount of oil actually burned were not possible, but the tanker was laden with 141,000 tons of Iranian heavy crude and very little remained in the wreck following the accident and fire. It was reported that several surveys during 1991 confirmed that there was sunken oil offshore and along the coast. The sunken oil is now thought to have resulted from the extraordinary heating of the contained product inside the cargo holds of the vessel. This oil basically underwent a crude distillation, in which lighter components were driven off and a denser—and in this case, heavier than sea water—material remained.

It should be emphasized that the circumstance specific to this situation should not be used as the basis for generalization in all burning scenarios.

6. SUMMARY OF POTENTIAL TRADEOFFS RELEVANT TO BURNING

As is the case with all response methods, the environmental tradeoffs associated with in situ burning are situation dependent and cannot be considered independently from operational tradeoffs. In situ burning can offer important advantages over other response methods in specific cases, and may not be advisable in others, depending on the overall mix of circumstances.

6.1. Advantages

- a) In certain areas where other techniques may not be possible or advisable due to the physical environment (e.g., ice conditions or wetlands) or the remoteness of the region, burning may represent one of the few viable response choices besides no action;
- b) In situ burning may prevent or significantly reduce the extent of shoreline impacts, including exposure of sensitive biological resources, wildlife habitats, and the oiling of high value recreational or commercial beaches;
- c) The magnitude of a spill may overwhelm the containment and storage equipment deployed or available for a region, necessitating the consideration of other methods in an overall response strategy;
- d) Burning can rapidly remove a large volume of oil from the surface of the water, reducing the magnitude of subsequent environmental impacts of stranded oil.

6.2. Disadvantages

- a) Large quantities of highly visible black smoke are generated that may adversely affect human and other exposed populations downwind;
- b) There may be the potential for mortalities and other adverse biological impacts from localized temperature elevations at the water surface. Although these could be expected to occur in a relatively small area, in specific bodies of water at specific times of the year, affected populations may be large enough or important enough to present reasons for not considering burning as a cleanup technique;
- c) The longer-term effects of burn residues on exposed biological populations have not been investigated. It is not known whether these materials represent a significant source of toxicity;
- d) In situ burning must be carefully controlled in order to maintain worker safety and to prevent unintended environmental impacts;
- e) There is a relatively short window of opportunity to use burning after a spill occurs prior to the oil weathering and losing its flammable characteristics.

7. MONITORING

The primary operational purpose in monitoring the burning of spilled oil is to determine whether burning requirements and objectives are met. Although the current body of knowledge about burning is limited, each operational use provides an opportunity to gather further information. Operational monitoring must occur during a response involving the use of in situ burning and must be accompanied by a detailed monitoring plan. More information regarding specific monitoring procedures and standards can be found in the Technical Appendices.

Operational monitoring should include such parameters as:

- type and amount of oil spilled;
- weather and sea conditions;
- trajectory of the slick and smoke plume;
- estimated volume of oil to be burned;
- estimated volume of oil burned and remaining;
- the effectiveness of residual material collection;
- adverse effects to natural resources (e.g., number of dead organisms).

In an effort to gather more data about in situ burning, spill-of-opportunity research possibilities involving a broad range of physical, biological, and chemical issues, are encouraged. Research monitoring might involve:

- collection of oil sample prior to burning for analysis;
- observations of residual material behavior and fate;
- collection of residual material for analysis;
- upwind and downwind air sampling;
- number and location of sampling stations;
- compounds (PAHs, particulates) to be monitored
- species and numbers of biota (e.g., waterfowl, aquatic organisms, vegetation) in the area.

Part II - Technical and Background Information

1. BURN EFFICIENCY

The efficiency of an in situ burn is usually expressed as the percent reduction in original oil weight following combustion. Researchers have found that oil thickness, degree of weathering, and degree of emulsification are among the most important factors affecting the efficiency with which oil will burn. The interaction among these parameters will determine the amount oil that is actually removed from the surface of the water during a burn.

Although the efficiency of in situ burning is highly dependent on a number of physical factors, test burns and applications in actual spill situations suggest that it can effectively remove large quantities of crude oil from the water. For example, Benner *et al.* (1990) found that 54 to 83 percent of an Alberta Sweet crude oil sample was burned in laboratory tests of in situ burning (the range in efficiencies correlated with oil layer thicknesses from 2 to 10 mm). Brown and Goodman (1986) measured burn efficiencies for Norman Wells crude in simulated ice floe conditions ranging from 67 to 90 percent (the higher efficiencies resulted when thicker layers of oil were burned).

In 1989, a test burn in the first days of the *Exxon Valdez* spill in Prince William Sound, Alaska, burned approximately 15,000 to 30,000 gallons of Prudhoe Bay crude oil, at an estimated efficiency of 98 percent or better (Allen 1990; Evans *et al.* 1990).

These removal efficiencies refer to the amount of oil burned once it is contained within a boom. It does not include the inefficiencies associated with collecting and containing the oil itself. Fingas *et al.* (1989) found that chemical dispersants could, in some cases, be very effective in removing crude oils from the water surface. They also determined that some oil-dispersant combinations had no effect. Solsberg *et al.* (1976) evaluated the effectiveness of seven skimmer-type oil recovery devices, and found a wide range of efficiencies in picking up spilled oil and in the amount of oil recovered relative to the amount of water recovered. With its consistently high efficiency in oil removal, in situ burning compares favorably with the best performances of these more familiar response techniques.

In situ burning has been tested most often with crude oil spills. Its feasibility with other kinds of products (e.g., marine diesel fuel and Bunker C fuel) has also been demonstrated (Twardus 1980), although inherent characteristics of the non-crude oils make them less amenable to the technique. That is, in situ burning is more effective in removing crude oil than other types of oil because of difficulties in establishing and maintaining necessary slick thicknesses (in the case of lighter, lower-viscosity oils) and difficulties with ignition (for heavier, less volatile oils).

A 1991 U.S. EPA summary noted the variant in burn efficiency with slick thickness: with a slick of 10 mm thickness, approximately 80 to 90 percent of the oil is burned; with a slick of 100 mm thickness, approximately 98 to 99 percent is burned (U.S. EPA 1991).

Alyeska (1992) commented that the effects of emulsification on burn efficiency are similar to, but more pronounced than, those for weathering. Similarly, Buist (1989) determined that oil burning efficiency also declined with increasing emulsification as shown below. Similar results were obtained by Bech *et al.* (1992). These observations again imply that two separate ignitions may be necessary for efficient product removal when the oil has emulsified. The first ignition would vaporize water from the slick, while the second ignition (after collection of the oil to thicken it) would burn off the oil. During spills, burn efficiency will also depend on wind speed, currents and ability to deploy and maneuver equipment.

Summary Table (Buist 1989)

Type of Emulsion Burn Efficiency (percent)

Unemulsified Hibernia Crude 85 - 90 25% water-in-oil 70 - 80 50% water-in-oil Hibernia B-27
70 - 75 75% water-in-oil Hibernia B-27 5 - 35 \geq 50% water-in-oil Hibernia C-96 0

2. AIRBORNE COMPONENTS OF IN SITU COMBUSTION

Most of the oil in an in situ burn will be converted to carbon dioxide and water. Particulates, mostly soot, comprise 10 to 15 percent of the smoke plume. Small amounts of toxic gases are emitted as well. These include sulfur dioxide, nitrogen dioxide, and carbon monoxide. In addition, small amounts of polynuclear aromatic hydrocarbons (PAHs) are emitted from the fire, mostly as residues attached to the particulates. These combustion byproducts are discussed below.

2.1. Sulfur dioxide

(SO₂)

Sulfur dioxide is a gas formed when sulfur in the oil oxidizes during the combustion process. This gas is toxic and irritates the eyes and respiratory tract by forming sulfuric acid on these moist surfaces (Amdur 1986).

The concentration of SO₂ in the smoke plume depends on the sulfur content of the oil. Average SO₂ level measured in experimental burns have been below 2 ppm in the plume 100 to 200 meters downwind of the burn (Fingas *et al.* 1993). Several miles downwind, sulfur dioxide from in situ burning is expected to be much below the level of concern for the general population.

Table 1. Major in situ burning pollutants and their exposure standards

Pollutant OSHA PEL* NAAQS SO₂ 2 ppm 0.14 ppm/24 hr NO₂ 1 ppm 0.05 ppm PAH 0.2 (volatile) _

CO 35 ppm 9 ppm PM-10 5 mg/m³ 0.15 mg/m³

*Time-weighted average concentration over 8 hours

2.2. Nitrogen dioxide (NO₂)

Nitrogen dioxide is another gaseous byproduct of oil combustion. Like SO₂, it is reactive, toxic, and a strong irritant to the eyes and respiratory tract. NO₂ is less soluble than SO₂ and therefore may reach the deep portions of the lungs (the critical gas exchange area of the lungs) so that even low concentrations may cause pulmonary edema, which may be delayed (Amdur 1986).

Sampling results to date indicate that the concentration of nitrogen dioxide in the plume several miles downwind of the burn does not exceed several parts per billion. Therefore, it is not expected to pose a threat to the general public several miles downwind of the burn.

2.3. Polynuclear aromatic hydrocarbons (PAHs)

PAHs are a group of hydrocarbons characterized by multiple benzene rings attached together. These compounds have very low vapor pressures and are not very flammable (compared to other compounds found in crude oils). PAHs are found in the unburned oil as well as the smoke plume. Some PAHs are known or suspected to be carcinogens. Target organs may include the skin (from chronic skin contact with oils) or the lungs from inhalation of aerosol. Based on data from NOBE and previous burns, most PAHs are burned in the fire, and their concentration in the oil residue is higher than in the smoke plume. Considering the low level of PAHs detected in these past burns, it is felt that they present only a small exposure hazard.

2.4. Carbon monoxide (CO)

Carbon monoxide is a common byproduct of incomplete combustion. The toxicity of CO is acute and stems from its high affinity to the hemoglobin molecule in red blood cells. CO will chemically displace oxygen from the blood and cause oxygen deprivation in the cells of the body. In experimental burns the average level of CO in the smoke plume over the duration of the burns (15 to 30 minutes) was found to be 1 to 5 ppm 150 meters downwind of the burns.

2.5. Particulates

Particulates in the smoke plume are considered by most health professionals to be the main combustion product to investigate and monitor. Therefore, particulates will be discussed in more detail.

Particulates are small pieces of solid materials (dusts, soot, fumes) or liquid material (mists, fogs, sprays) that remain suspended in the air long enough to be inhaled. During in situ burning, elemental carbon (soot) and hydrocarbons are emitted. Since these particles absorb light to a high degree, the smoke plume is usually black.

Particulate concentration is measured in several ways. A relatively accurate method involves sampling with an air pump that draws air through a filter. Depending on pore size, the filter may collect more than 99.9 percent of the particulates in the air. Real-time instruments that can measure particulate concentration at the time of measurement are also available; some are quite sensitive and accurate. They must be calibrated to the particulates of concern, and may be affected by other aerosols such as water vapor.

Since 10 micrometers (:m) in diameter is the size below which particulates may reach the deep portion of the lungs and become a burden on the respiratory system, most scientists tend to divide the particulate mass into "total" particulates, which include any size measurable, and "PM-10," which is the fraction of particulates smaller than 10 :m in diameter.

Particulate size also plays a crucial role in determining how long they will be suspended in the air. Larger particulates (tens of μm in diameter) would precipitate rather quickly close to the burning site. Smaller particulates (ranging from a fraction of a μm to several μm in diameter) would stay suspended in the air for a long time and be carried over long distances by the prevailing winds. Particulates small enough to be inhaled (PM-10) are also the ones to remain suspended. A practical implication is that if those particulates do not descend to ground level (where people are) they will not threaten the population downwind. For most people, exposure to inert respirable particulates may become a problem at high concentrations (several milligrams of particulates per cubic meter of air). However, sensitive individuals may develop respiratory problems at levels much lower than that. Several recent studies (Schwartz 1992; Pope *et al.* 1992; Dockery *et al.* 1992) suggest that there is a correlation between particulate concentration in the air and daily mortality. These studies used measurements of air pollution and matched them to mortality and morbidity data in several cities in the U.S.: Philadelphia, Detroit, Provo, and Birmingham, Alabama. Higher levels of PM-10 were associated with increase in daily morbidity and mortality, especially among older people and people with allergies, respiratory problems, and cardiovascular diseases. An increase of $100 \mu\text{g}/\text{m}^3$ of the measured daily particulate level was associated with 6 percent increase in mortality (Schwartz 1992). The biological mechanism has not been determined, but the possibility of such a correlation should dictate that in situ burning be conducted only when it does not pose a hazard to human health, and exposure to particulates should not exceed the applicable Federal or State standard.

Sampling conducted so far indicates that the populations downwind and even response personnel will be exposed to very low levels of gases and particulates. In the recent experimental in situ burn off the coast of Newfoundland, many particulates were tagged with sampling badges to assess their exposure to volatile organic compounds (VOCs). Initial analysis of those badges indicates that exposures in most cases were below the level of detection (LOD=0.001 mg per sample). The few detected VOC "hits" could be traced to fuel and solvents on the vessels rather than VOCs from the spilled or burning oil (Bowes 1994). Similarly, the level of respirable particulates (PM-10) was monitored by a University of Washington research aircraft. While concentration of PM-10 at or above 150 micrograms per cubic meters ($\mu\text{g}/\text{m}^3$) of air extended to a distance of approximately 6 miles in the plume itself, PM-10 concentration beneath the plume, 150 to 200 feet above the surface, did not exceed background levels of 30 to 40 $\mu\text{g}/\text{m}^3$ (Ferek personal communication). These data agreed well with previous measurements done in test burns in Mobile Bay, Alabama.