In-Situ Burning

In-situ burning, or **ISB**, is a technique sometimes used by people responding to an oil spill. In-situ burning involves the controlled burning of oil that has spilled from a vessel or a facility, at the location of the spill. When conducted properly, in-situ burning significantly reduces the amount of oil on the water and minimizes the adverse effect of the oil on the environment.

Frequently Asked Questions (FAQ)

Here are answers to questions that are frequently asked about ISB:

- General Questions
- Environmental Tradeoffs
- Environmental Impacts
- Human Health Concerns
- Safety Concerns
- Economic Concerns
- Institutional Concerns

ISB Guidelines and Handouts

- Guidance on Burning Spilled Oil In Situ - A position paper from the National Response Team (NRT) on the recommended limits for short-term human exposure to particulates measuring less than 10 microns (PM-10) while spilled oil is burned in situ.
- Open-Water Response Strategies: In-Situ Burning - Why conduct in-situ burning? How is it done? What about the emissions that it produces? Where has in-situ burning been conducted? What factors might prevent its use?
- **Regional Response Team VI** Guidelines for Inshore/Nearshore In-Situ Burn - Advantages and disadvantages of in-situ burning of oiled wetlands, safety and

operational guidelines, and a checklist for in-situ coastal wetland burns.

- In-Situ Burn Unified Command Decision Verification Checklist - This checklist, created with input from the Region II Regional Response Team, summarizes important information the Unified Command should consider when planning oil spill in-situ burning in marine waters of Region II.

Health and Safety

- Health and Safety Aspects of In-situ Burning of Oil - Presents health and safety considerations for response personnel, the general public, and the environment.
- Sample Site Safety Plan for Marine In-situ Burn Operations - A draft sample site safety plan that includes elements unique to ISB. The sample is not a standard, but rather a suggested starting point.

Fate and Effects

- Residues from In-Situ Burning of Oil on Water - Surveys current knowledge of the behavior and effects of ISB residues.

ISB Comparisons

The particulates released into the atmosphere by in-situ burning are a concern to many people. Here are comparisons between in-situ burning emission rates and rates of emission from other kinds of sources.

Monitoring ISB: SMART

SMART (Special Monitoring of Advance Response Technologies) is a monitoring protocol for both in-situ burning operations and dispersant application. The ISB module of SMART provides guidelines for monitoring the smoke plume from ISB operations.

- SMART Page - Basic information about the SMART monitoring program for in-situ burning and dispersants.

From:
Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration

Frequently-Asked Questions

General Questions

Here are answers to some questions that people have asked about general in-situ burning topics.

Q. What is in-situ burning (ISB)?

A. ISB involves controlled burning of oil that has spilled from a vessel or a facility, or burning oil on the vessel itself before it has a chance to spill into the environment. When burning is done on open water, the oil is contained within a boom and ignited using a hand held igniter, or an igniter from a helicopter. The burn continues only as long as the oil is thick enough--usually about 1/10 of an inch or 2 to 3 millimeter. When conducted properly, in-situ burning significantly decreases the amount of oil on the water, thereby preventing that oil from reaching the shore. Burning can be a useful tool in oil spill response.

Q. Is ISB an effective way to remove oil from the water?

A. Although the efficacy of ISB is highly dependent on a number of physical factors, test burns and applications in actual spill situations suggest that ISB can be very effective in removing large quantities of oil from the water. Under the right environmental and oil conditions, burning can remove up to 95-98% of contained oil from the water. While all spilled oil cannot generally be burned, ISB can remove large quantities of oil from the water, preventing or significantly reducing the extent of shoreline impacts.

ISB is more effective in removing crude oil than other types of oil from the water surface. With lighter, lower viscosity oils, it is difficult to maintain the necessary slick thickness; heavier, less volatile oils are difficult to ignite.

Q. Does the spill response community compare the potential harm to the air versus the water and surrounding environment?

A. Yes. The goal when conducting in-situ burning is to protect the environment as much as possible while ensuring that air pollution impacts do not jeopardize human health. Uncollected oil can adversely affect wildlife, fish, recreational beaches, and the rest of the marine environment for a long time. Usually, the air pollution impacts of a burn are short-lived, but they may be substantial. A smoke plume caused by the burning of oil will usually be confined to a relatively narrow band that may stretch for some miles, while uncontained oil will likely be taken by the currents over a wide geographic area.

An oil spill causes air pollution whether or not burning is used. Therefore, responders must consider the relative risks of evaporating vapors against the smoke created by burning. Vapors from a large spill in a populated area could pose a significant health threat. Up to 50 percent of a light crude oil spill can evaporate fairly readily, and that 50 percent contains the acutely toxic, lighter fractions, or volatiles, that move quickly into the atmosphere. The volatiles released from spilled oil may be more toxic to humans than the smoke from burned oil, depending on the concentrations. They may contain volatile organic compounds, including benzene (a known human carcinogen), toluene, xylene, hexane, and others. Whether the oil is burned or allowed to evaporate, air quality will be compromised for a certain period of time.

Q. Why do we have to burn the oil? Why not just clean it up?

A. In-situ burning is one of several options available to combat a spill. It should **complement** other options, not exclude them. When possible, spill responders start mechanical recovery immediately, using booms, skimmers, and other equipment. When feasible to carry out, in-situ burning is fast and efficient. It can remove up to 99 percent of the oil contained in the boom, and reduce the need for storage and disposal. When it is safe and environmentally wise to use in-situ burning, the environment benefits because more oil will be removed from the water.

Q. Under what circumstances can in-situ burning occur?

A. There are a number of physical limitations that restrict the feasibility of burning, including wind speed, wave height, oil type, and the degree of emulsification of the oil (how much it has mixed with the water). The basic criteria are that:

- human populations will not be exposed to smoke that exceeds state and federal health standards.
- the burn must be monitored for the safety of cleanup crews and potentially affected populations, and will be stopped if safety standards cannot be maintained.
- sea and weather conditions must allow for an effective burn.

Q. What if the weather changes? Can the fire be put out?

A. Monitoring will be conducted to ensure conditions remain appropriate for a burn. (More information about monitoring in-situ burning is available **here**.) If conditions do not remain appropriate, a burn on open water can be extinguished very quickly simply by releasing the end of the boom containing the oil. This allows the oil to spread to its natural thickness, which is ordinarily too thin to sustain combustion. When a burn is done on a ship or on land, extinguishing the burn is difficult, and in some cases, impossible.

Q. What does the smoke contain? Are the emissions from the fire harmful?

A. Burning oil produces a dense cloud of black smoke. The dark color of the smoke is due to very small black particles of carbon. Very fine particles can lodge inside the lungs and cause respiratory problems, mostly to individual already suffering from other respiratory diseases. Other substances can adhere to particles and be inhaled. While it is generally long-term (months or years) exposure to these small particles that impact health, short-term exposure in sufficient concentrations can cause the aggravation of symptoms in sensitive individuals with existing heart or lung disease.

An oil fire also produces water vapor and invisible gases, mainly carbon dioxide, carbon monoxide, sulfur dioxide, and oxides of nitrogen. Studies of the gases produced by oil fires show that the concentration of gases produced during in-situ burning are within safe levels for humans beyond three miles downwind of the source. Oil is composed of hundreds of hydrocarbons, some of which don't burn completely. As a result, the emissions from the fire can include hydrocarbons, including very low levels (less than 0.1 parts per million) of polyaromatic hydrocarbons.

The by-products of burning oil are similar to those from the burning of other products, such as firewood and fuel for cars, trucks, home furnaces, and factories. The main difference between ISB and other burns is that oil doesn't burn very efficiently during ISB, and produces particulates that give the smoke its dark color.

Q. What health standard do responders use when considering a burn?

A. Spill responders use an especially stringent outdoor air quality standard to guide their burning decisions. Fine-particle pollution is the major concern in evaluating health effects from smoke. These particles are defined as those less than 10 microns (thousandths of a millimeter) in diameter. (Fifty 10-micron particles would stretch across the period at the end of this sentence.) The current national and state health standard is a maximum concentration in a 24-hour period of 150-micrograms of fine particle per cubic meter of air.

Some health professionals do not believe that the current standard of 150 micrograms per cubic meter of air averaged over a 24-hour period adequately protects the health of sensitive individuals, such as children or those with existing heart or lung disease. New research has prompted a review of the existing standard that could lead to a more protective standard. Based on recommendations by the Centers for Disease and Prevention (CDC) and other federal agencies, the National Response Team has recommended to federal response officials that the level of concern be set at **150 micrograms per cubic meter of air averaged over one hour**, which is much more stringent than the 24-hour measurement.

Q. How much smoke should I expect from the burn? How long will it stay in the air?

A. Because of the intense heat, the smoke plume from an oil fire usually goes up into the atmosphere several hundred to several thousand feet. It then levels off and moves according to the weather conditions. How long the smoke stays in the air depends on the wind direction and weather conditions at the time of the burn. Some parts of the plume may dip back down toward the surface, but most of the smoke usually stays well up in the air and dissipates as it is carried away by the prevailing wind. Parts of the plume may stay in the general area of the burn for several hours after a burn is completed, but the thickest part of the plume usually dissipates within a short period of time.

Q. Shouldn't we be more worried about preventing spills, instead of burning them?

A. Absolutely! Preventing spills is our number one priority. The oil industry and certain state and federal agencies are working hard to find ways to prevent spills from happening. It is far less costly to prevent spills than to clean them up. There are both federal and state laws and regulations that address prevention. Despite everyone's efforts, however, spills happen, and the response community must be prepared to use all appropriate tools to respond effectively.

From:
Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration

Frequently-Asked Questions

Environmental Tradeoffs

Here are answers to questions that people have asked about the environmental tradeoffs of using in-situ burning (ISB).

Q. What are the potential environmental tradeoffs relevant to the use of in-situ burning?

A. As with all response methods, the environmental tradeoffs associated with in-situ burning must be considered on a case-by-case basis and weighed with 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 circumstances of a spill. In general, these are some of the pros and cons of ISB:

Pros:

- In-situ burning is one of the few response methods that can potentially remove large quantities of oil from the surface of the water with minimal investment of equipment and manpower.
- Burning may offer the only realistic means of removal that will reduce shoreline impacts in areas where containment and storage facilities may be overwhelmed by the sheer size of a spill, or in remote or inaccessible areas where other countermeasures are not practicable.
- If properly planned and implemented, in-situ burning may prevent or significantly reduce the extent of shoreline impacts, including exposure of sensitive natural, recreational, and commercial resources.
- Burning rapidly removes oil from the environment, particularly when compared to shoreline cleanup activities that may take months or even years to complete.
- In-situ burning moves residues into the atmosphere, where they are dispersed relatively quickly.
- Control of burn activities is relatively simple, provided containment is appropriate.

Cons:

- In-situ burning, when employed in its simplest form, generates large quantities of highly visible smoke that may adversely affect humans and other exposed populations downwind.

- Burn residues may sink, making it harder to recover the product and to prevent the potential exposure of benthic (bottom-dwelling) organisms.

- Plant and animal deaths and other adverse biological impacts may result from the localized temperature elevations at the sea surface. While these affects could be expected to occur over 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 reconsider burning as a cleanup technique.

- The long-term effects of burn residues on exposed populations of marine organisms have not been investigated. It is not known whether these materials would be significantly toxic in the long run.

- The burn must be carefully controlled in order to maintain worker safety.

Q. Isn't burning just trading water pollution for air pollution?

A. Air pollution from an in-situ burn is usually short-lived and consists mainly of smoke particulates. In certain concentrations, these particulates may be harmful to some persons. However, unburned oil is also a source of air pollution, mainly from evaporating hydrocarbon compounds that also present health hazards. These compounds also contribute to the formation of smog.

Q. Does ISB preclude other spill response measures?

A. There are three primary cleanup methods: in-situ burning, dispersants, and mechanical methods. Whether or not burning would limit the use of other spill response measures depends on the circumstances of a spill. In a major spill, it may be possible for all response techniques to be used simultaneously. The goal is to find the right mix of equipment, personnel, and techniques that will minimize a spill's environmental, socioeconomic, and cultural impacts.

Q. Are there long-term impacts to the environment from spilled oil?

A. Yes, oil spills can have serious long-term impacts to the environment. The long-term impacts to birds and mammals include lower reproduction rates and physical mutations in offspring. Harmful oil components can contaminate fish that are in turn eaten by other fish, seabirds, and humans, thus passing these harmful components up the food chain. Once oil is trapped in sediments, it can be recirculated into the water and remain in the food chain for many years. Some research indicates that oil can remain in sediments for hundreds of years.

From:
Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration

Frequently-Asked Questions

Environmental Concerns

Here are answers to some questions that people have asked about environmental issues.

Q. What are the potential ecological effects of in-situ burning (ISB)?

> A. The potential ecological impacts of ISB have not been extensively discussed or studied. Burning oil on the surface of the water could have a small adverse effect on organisms that inhabit the uppermost layers of the water column (such as fish larvae and eggs); however, the area affected would presumably be small relative to the total surface area and depth of a given body of water. In addition, burn residues may sink, potentially exposing some benthic (bottom-dwelling) plants and animals. It is possible that burn residues may foul gills, feathers, fur, or baleen. Overall, these impacts would be expected to be much less severe than those resulting from exposure to a large, uncontained oil spill.

Q. What are the impacts of a large, uncontained spill?

> A. Oil spills can destroy fisheries, contaminate shellfish beds, injure archeological sites, coat recreational beaches, harm or kill wildlife, and destroy coastal habitat. Oil that comes into contact with mammals and birds can destroy the insulating ability of fur and feathers, reduce buoyancy, and be ingested as the animal cleans itself. Animals in a spill area can die of exposure, drowning, internal bleeding, and suffocation. Wildlife vulnerable to oil spills include shorebirds, bald eagles, sea otters, sea lions, harbor seals, and terrestrial mammals that may feed on oiled carcasses. There is also some evidence suggesting that oil spills may be linked to whale deaths.

Q. What effect does ISB have on shoreline contamination?

> A. Shoreline effects are usually minimized when ISB is conducted. Properly planned and implemented, in-situ burning can prevent or significantly reduce the extent of shoreline impacts, including exposure of sensitive natural, recreational, and commercial resources.

From:
Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration

Frequently-Asked Questions

Human Health Questions

Here are answers to some questions people have asked about in-situ burning and human health.

Q. What are the human health concerns related to ISB?

A.The smoke produced by burning crude oil is a mixture of heated gases and coated carbon particles, which are products of combustion and pyrolysis. Gaseous combustion products include carbon monoxide, carbon dioxide, sulfur oxides, nitrogen dioxide, and various polynuclear aromatic hydrocarbons. **The primary human health concern is the particulate matter in the smoke plume. Of specific concern are the very small particles 10 microns or less in diameter (a micron equals one-millionth of a meter, or 0.0004"). These particles are commonly referred to as "PM 10" and are small enough to lodge in human lungs.** It is generally long-term exposure, over months or years, to PM 10 that affects human health. However, short-term exposure to high concentrations can aggravate symptoms in sensitive individuals with heart or lung ailments.

Although ISB presents some health concerns, an oil spill causes air pollution whether or not it is burned. Analysis of the physical behavior of spilled oil has shown that 50% of a light crude oil spill can evaporate fairly readily, and that it is the acutely toxic lighter fractions of a crude oil mix that quickly move into the atmosphere. The volatiles released from spilled oil contain polyaromatic hydrocarbons, including benzene (a known human carcinogen) and toxic fumes, such as toluene, xylene, butane, and propane. Whether the oil is burned or allowed to evaporate, air quality will be compromised for a certain period of time. Responders must consider the relative risks of evaporating fumes against the smoke created by burning.

Q. What health standard do responders use when considering a burn?

A. The current national and state health standard, based on EPA's National Ambient Air Quality Standard, states that PM 10 levels should not exceed 150 micrograms of PM 10 per cubic meter of air averaged over a 24-hour period. The National Response Team (NRT) has developed more restrictive PM 10 guidelines for in-situ burning. **The NRT recommends a maximum concentration of 150 micrograms of PM 10 per cubic meter of air averaged over a 1-hour period.**

Q. Why do you use a particle standard that is more restrictive than existing law?

A. Some health professional do not believe that the current standard of 150 micrograms per cubic meter of air averaged over a 24-hour period adequately protects the health of sensitive individuals, such as children or those with heart or lung disease. Restricting the measurement period from 24 hours to 1 hour better protects these members of the population.

Q. What residue will remain after a burn?

A. If the burning procedure is successful, there will be a small quantity of residue left (less than 2% of the original oil volume), which will be collected, but may sink in the area of the burn. The amount and characteristics of the residue will vary according to oil type.

Q. What will be the air quality during a burn?

A. The air quality in your community will be no different than it would be in normal situations. The burning procedures require that the smoke from the fire travel away from populated areas, and that the burn be terminated should the wind direction change.

Q. Why would you consider burning an oil spill when people are not allowed to use their woodstoves on some days during the winter?

A. Woodstoves represent a continuing, persistent source of airborne pollutants that can have a detrimental effect on human health. In-situ burning of accidentally spilled oil occurs very infrequently, and will last for a short period of time--typically a few hours. Moreover, an oil spill is an emergency situation that may require extraordinary measures. Those responsible for responding to a spill may conclude that a temporary source of airborne pollutants is necessary to achieve the overall goal of reducing the environmental effects of spilled oil.

Q. Will I have to leave my home if a burn is conducted near where I live?

A. Ordinarily, those in charge of responding to a spill would not approve in-situ burning if it is necessary for people to leave their homes. It is possible, however, that in unusual situations, burning the oil would be necessary even if it meant that people needed to leave their homes. If that were to occur, the local and state health departments would be consulted to ensure people's safety.

From:
Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration

Frequently-Asked Questions

Safety Questions

Here are answers to some questions that people have asked about safety issues.

Q. What are the safety concerns related to in-situ burning (ISB)?

A. Burning presents some unique safety concerns for workers and response personnel. These are some of the concerns:

Fire Hazard: ISB is a process that involves setting fires. Extreme care must be taken so that the fires are controlled at all times, and will not harm personnel or equipment.

Ignition Hazard: Planners must carefully consider the ignition of the oil slick. Aerial operations to ignite oil with gel or other ignition methods must be well-coordinated. Weather and water conditions should be kept in mind, and proper safety distances should be observed at all times. Communication with all personnel is essential.

Vessel Safety: ISB at sea involves several vessels working in relatively close proximity to each other or in poor-visibility conditions. Such conditions are hazardous by nature, and require practice, competence, and coordination.

Other Hazards: Personnel involved in ISB may be exposed to extreme heat from the compounded effects of hot weather and fire, or extreme cold, in places like Alaska. Working under time constraints may impair judgment or increase the tendency to attempt costly shortcuts. Thorough training and strict safety guidelines must be part of any ISB operation.

Q. How do you control an ISB and avoid spreading of the fire?

A. The fire is usually contained in a fire resistant boom. Oil can be burned in an area physically remote from other sources of oil, or a boom can be used to isolate oil for burning. The goal of ISB is to avoid accidentally igniting oil outside the boomed area. If there is a potential of igniting oil outside the boomed area, burning will not be conducted.

Q. Is burning the oil safer than other clean-up methods?

A. All clean-up methods have safety concerns for the responders. Response personnel involved in ISB are trained and outfitted to conduct this procedure in a safe manner. In addition, safety and human health specialists monitor their operations for safety.

Frequently-Asked Questions

Economic Concerns

Here are answers to some questions about in-situ burning's effect on the economy.

Q. What effect does in-situ burning (ISB) have on the fishing industry?

A. One of the reasons a burn is done is to prevent adverse effects to marine life, including fish. ISB should not have any adverse effects on the fishing industry.

Q. What will be the water quality after a burn?

A. Because burning will remove almost all of the contained oil from the water surface, water quality should not be affected. After a burn, responders may sample the water, which provides them with a better overall assessment of the water quality in the area.

Q. What should I do to protect my house and business during a burn?

A. Generally, there is no need for you to take any special actions to protect your home or business. In-situ burns are usually conducted at sea and the burning procedure eliminates most of the oil in a safe and efficient manner. The response organizations will keep you updated before and during the burn and will notify you if there are any measures you should take.

Q. How soon after a burn can recreational boating resume?

A. The response organizations generally establish a safety zone around the burn. You may continue to use boats outside of this zone, as directed by the U.S. Coast Guard. The zone will be opened as soon as the response is completed.

From:
Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration

Frequently-Asked Questions

Institutional Issues

Here are answers to some questions that people have asked about the institutions that conduct in-situ burning (ISB) as an oil spill response.

Q. Who makes the decision to conduct a burn? Is it the responsibility of local, state, or federal authorities?

A. The use of ISB as an oil spill response tool is regulated by both federal and state law. Regional Response Teams, made up of federal and state agencies, have developed guidelines that provide a common decision-making process to evaluate the appropriateness of using ISB during a spill response. **The Federal On-Scene Coordinator, in consultation with the State On-Scene Coordinator, has the authority to approve ISB.** When deciding whether to conduct ISB, the coordinators consult with air quality experts, meteorologists, response contractors, and experts on burning.

Q. How soon does a decision to burn have to be made?

A. The decision to burn generally needs to be made within the first few hours following a spill. Because spilled oil rapidly emulsifies, it becomes more difficult to ignite with time. If the weather and sea conditions are very calm, the time frame may be extended; however, the decision must be made quite quickly because it takes time to assemble the personnel and equipment necessary to conduct a burn.

Q. How will I be notified if there is going to be a burn in my area?

A. The local, state, and federal response organizations involved in the response will meet with elected officials, the public, and the media to discuss the response and the activities currently taking place. Monitor your newspaper, radio, and television for current reports and announcements of meetings in your area.

Q. Who pays for a burn?

A. The federal government insures that the spill area is cleaned, but the spiller is generally responsible for all costs associated with the cleanup, including an in-situ burn.

From:
Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration

NATIONAL RESPONSE TEAM
Science & Technology Committee

GUIDANCE ON BURNING SPILLED OIL IN SITU
December 1995

BACKGROUND

On October 3, 1993, the Alaska Regional Response Team (RRT) requested a position paper from the National Response Team (NRT) on the recommended limits for short-term human exposure to particulates measuring less than 10 microns (PM-10) while spilled oil is burned in situ. To respond to this request, the NRT asked its Science and Technology Committee to obtain guidance from the Centers for Disease Control and Prevention (CDC) and the Occupational Safety and Health Administration (OSHA). CDC and OSHA, working through the Science and Technology Committee, convened a workgroup of public health and oil-spill specialists to review existing data on the subject, discuss appropriate exposure levels, and identify any remaining gaps in the data on the public health implications of burning oil. The meeting took place on June 21 and 22, 1994, in Atlanta, Georgia. A draft report of recommendations from the meeting was forwarded to the Science and Technology Committee, which made minor revisions to the report based on agencies' comments and recent research results from experimental burns. This document was then forwarded to the NRT for concurrence and distribution.

These recommendations are designed to assist RRTs in developing contingency plans for burning spilled oil in situ. Discussion Items 1 through 3 refer to issues concerning the general population in the areas where the oil will be burned. Discussion Item 4 refers to issues relating to workers and emergency responders. Attached is a workgroup-reviewed background document on health and safety issues associated with burning spilled oil in situ. A list of research priorities is also attached, based upon discussions from the Atlanta workshop and subsequent discussions by the NRT S & T Committee.

[NOTE: At the time of publication of this document, EPA was under a court order to review and revise, if necessary, the PM-10 National Ambient Air Quality Standard by January 1997. EPA was considering a PM fine standard that would address particulates less than 2.5 microns in diameter. If EPA does revise or amend the PM-10 standard or if there is any other formally promulgated standard relevant to this issue, this guidance will be revised, and RRTs should re-evaluate their ISB contingency plans accordingly.]

DISCUSSION

Item 1. Acceptable Distance from the General Population for Burning Spilled Oil In Situ

The selection of an acceptable distance from population centers at which to burn spilled oil should be based primarily on the extent of the potential for human exposure to the smoke. Distances should be set so as to minimize the chance for excessive public exposure to particulates, even if the plume touches down. Therefore, if the wind is blowing away from population centers, the spilled oil may be burned close to these areas. If, however, the wind is likely to carry the smoke in the direction of a population center, more caution is needed. If there is no real-time air sampling for PM-10 during the burn, a distance should be selected at which smoke plume trajectory modeling or actual burns in similar environmental and meteorological conditions have shown that the maximum concentration of particulates does not exceed the level of concern (which is discussed in Item 2). A margin of safety should be included for burns where no sampling or only limited sampling will be conducted. If real-time sampling for PM-10 is part of the monitoring procedure during the burn, then the process of selecting an acceptable distance is more flexible. In such a case, feedback from samplers will assist in determining whether exposure to the public is likely to be excessive and whether burning should be terminated.

Item 2. PM-10 Level of Concern for General Populations

Levels of concern for public health associated with burning spilled oil in situ should be assessed in the context of the effect of oil spills in general and the risk the spill poses to people and the environment. The impact of a temporary reduction in air quality from particulates due to burning should be weighed against the impact of an untreated spill on the environment. A large percentage (20%-50%) of the spilled oil will evaporate and cause a temporary reduction in air quality from volatile organic compounds. In other words, whether the oil is burned or allowed to evaporate, air quality will be compromised. The decision whether to burn, or to continue to burn, must be made in consideration of all of the risks and tradeoffs posed to human health and the environment by the spill and the available countermeasures. These issues should be discussed and resolved during the planning process.

The Environmental Protection Agency established a National Ambient Air Quality Standard for PM-10 of 150 μg/m3 averaged over 24 hours, a standard considered protective of public health. We recommend that burning spilled oil in situ should not increase PM-10 levels in ambient air above that standard. This means that spilled oil can be burned in situ if it does not increase PM-10 exposure of the general population beyond the national standard. It also means burning is not recommended if the air quality in the region already exceeds the 150 μg/m3 limit and burning the oil will add to PM-10 exposure of the general population. Burning is still feasible in such a region if PM-10 exposure of the general population is not increased. In cases where state or local standards are more stringent than national standards, differences should be resolved in the contingency planning process.

Because spilled oil will probably be burned for short durations, averaging the resulting concentrations over 24 hours may be inappropriate. Until data are available to justify raising the allowable concentration levels for short periods, there is no scientific justification for recommending a short-term concentration level other than 150 μg/m3. Pending the results of current and planned research and development of in situ burning and risk assessment, we recommend a conservative upper limit of 150 μg/m3 averaged over 1 hour while burning spilled oil in situ. This recommendation will be continually evaluated and may be modified as results of test and actual in situ burn data become available.

The 150 μg/m3 concentration level should not be considered a fine line between safe and unsafe; rather it is a general guideline. If it is exceeded substantially, human exposure to particulates may be elevated to a degree that justifies terminating the burn. If particulate levels are generally below the limit, with only minor transitory incursions to higher concentrations, there is no reason to believe that the population is unacceptably exposed above the accepted National Ambient Air Quality Standard from the burn. This assumption is strengthened by the fact that the spilled oil normally will not be burned continuously for 24 hours.

The same assumption applies to monitoring the air with real-time instruments while the oil is burning. These instruments give instantaneous data and can be set to average their readings for several seconds to several hours. If instruments average their readings over a 15 minute period, individual readings should not be used to determine whether the burn should continue (one reading may be elevated because of a transient smoke source nearby); rather readings should be used as a group to ascertain a trend. The recommendation to continue burning or to stop should be based on trends and not a single measurement.

Item 3. Appropriate Monitoring Strategies

It is important to make a distinction between monitoring and sampling. For documentation purposes, a burn can be monitored visually without using any instrument other than a camcorder or a camera. The burn should be monitored when the resulting smoke poses a risk to an adjacent population.

Sampling involves measuring the concentration of smoke constituents in the environment. Environmental sampling for PM-10 should be conducted in the immediate vicinity of the population that may be affected. We understand, however that the decision to sample and how to sample may depend on the resources available for conducting the sampling and local guidelines. The RRTs and any affected state should resolve these issues in the planning process and integrate the results of their deliberations into the contingency plans for burning spilled oil in situ. In some parts of the country, sampling will be required by local guidelines. In others, it will not. Sampling protocols should be developed and agreed upon during the planning process.

Item 4. Safety and Health Guidance for Responders

Workers involved with in situ oil burning operations have the same rights to a safe and healthful work environment as any other worker under the Occupational Safety and Health Act. Such workers include responders, contractors, government workers, and other related employees. Worker protection from hazards associated with in situ burning is the responsibility of their employer. Employers must be aware of OSHA's safety and health regulations (and any local or state regulations) applicable to burning spilled oil in situ. Employers must have safety programs, identify hazards, establish emergency procedures, provide proper personal protective equipment, and provide required training. They should also recommend some additional safety measures, such as the use of a helitorch or other ignition device, may also be needed. In the absence of specific requirements, the Occupational Safety and Health Act stipulates that employers have a "general duty" to provide a safe and healthful workplace to their employees.

If personnel from nearby ships are asked to assist with the burning (as was the case in the burning conducted after the Exxon Valdez spill) they must have received all the necessary safety and health training and must be current on any post-training requirements.

RECOMMENDATIONS

Airborne particulate concentrations are not the only issue to be considered in the decision whether to burn or continue burning. The risks posed by in situ burning must be considered among all the risks posed to human health and the environment by oil spills and the countermeasures available to the On-Scene Coordinator. These trade-offs should be discussed and resolved by the RRT in the planning process. This planning process should include coordination with the appropriate EPA Regional office and State air pollution agency to identify all applicable regulations and requirements. It is also recommended that materials be prepared during the planning process to be available during a response. Should a burn be considered, these materials could be used to inform the public. Such materials can be provided as Public Service Announcements or through other similar media channels.

To minimize exposure of general populations to PM-10 from burning oil in situ, we recommend the following:

1. Select the acceptable distance from population centers for burning oil in situ on the basis of the potential for human exposure to the smoke.

2. Until better data are available, plan not to expose population centers to a conservative concentration level of 150 μg/m3 of PM-10 averaged over 1 hour .

3. Plan to terminate the burn if a change in wind direction or other weather conditions will cause the recommended exposure level to be exceeded.

4. Plan to measure particulate levels during the burn by environmental sampling in the immediate vicinity of any potentially affected population.

5. If no sampling is planned, select the allowable distance from the burn to downwind populations on the basis of data from smoke plume trajectory models or actual burns in a similar environment that show that the population's maximum exposure to PM-10 does not exceed the level of concern. Include a margin of safety for burns where no sampling or limited sampling will be conducted.

RESEARCH PRIORITIES

1. Develop accurate data on how far downwind PM-10 generated from an oil spill burn is measurable;

2. Develop/locate improved, less costly, and deployable monitoring equipment and technology for real time measurement of PM-10 during oil burns;

3. Test the validity of smoke plume trajectory models, which include features such as terrain, through field measurements;

4. Develop scientifically based information on the health effects of short-term exposure to PM-10 generated from oil spill burns;

5. Develop improved strategies for monitoring people's exposure and the concentration levels in the environment in order to assess public health risks;

6. Develop improved means of determining the health and safety consequences and trade-offs associated with in situ burning and alternative countermeasures; and

7. Develop a simplified smoke plume trajectory model for use in screening different burn scenarios during burn plan development.

Open-water Response Strategies: In-situ Burning

What is in-situ burning?

"In-situ" is Latin for "In-place." In-situ burning involves controlled burning of oil that has spilled from a vessel or a facility, at the location of the spill. Typically, the oil is contained within a boom and ignited using a hand-held igniter or an igniter suspended from a helicopter. The burn will continue only as long as the oil is thick enough—usually about 1/10 of an inch or 2 to 3 millimeters. When conducted properly, in-situ burning significantly reduces the amount of oil on the water and minimizes the adverse effect of the oil on the environment.

Why conduct in-situ burning?

When a spill occurs it is best to minimize the spread of the oil slick and remove as much of the oil as possible at the site of the spill. In-situ burning may provide a response method to help achieve this goal. Under favorable conditions in-situ burning is a fast, efficient, and relatively simple way of removing spilled oil from the water. Furthermore, it greatly reduces the need for storage and disposal of the collected oil and the waste it generates. When an oil spill occurs in ice-covered water or in a marsh, in-situ burning may be the only spill response method available. In-situ burning, however, should complement, not exclude, other means of spill response. When possible, spill responders start mechanical recovery immediately, using booms, skimmers, and other equipment. They may also use dispersants if conditions allow it.

How is in-situ burning done?

On open water, in-situ burning is likely to be done by two boats towing a fire-resistant boom in a U configuration. The open end of the U is maneuvered through the oil slick and a "boomful" of oil is collected. The boom is towed away from the main slick and the oil is ignited. During the burning, the pooled boom slowly advances ahead of the current to ensure that the oil is concentrated at the back end of the boom and maintains maximum thickness. After the oil is burned, the process may be repeated for as long as in-situ burning is feasible.

When a spill occurs in a river and the current is not too swift (below one knot) a fire-resistant boom may be anchored across the river to collect the oil. When the oil layer in the boom is thick enough, the oil is ignited.

In both cases it is possible to stop the burn by releasing one end of the boom, or by towing it faster so that the oil is no longer contained.

In-situ burning has been done successfully on numerous occasions when oil was trapped in ice, or spilled into sensitive marshland. Unlike burning on open water, burning on land is more difficult to extinguish.

What are the limiting factors?

One of the disadvantages of in-situ burning is that any of a number of factors may prevent its use.

Environmental

Oil thickness

In order to burn on the water, oil has to be thicker than 1-2 millimeters. During combustion the oil vapors ignite and burn, rather than the liquid itself. About 2-3% of the heat generated by the combustion is returned to the oil layer where it causes additional vapors to escape and burn (Buist 1994). When the oil layer is thinner than 1-2 mm, the heat is lost to the water, not enough vapors are released, and combustion ceases.

Waves and wind

Experiments have shown that in-situ burning is possible only under relatively calm conditions. When winds are stronger than approximately 20 knots and waves are higher than 3 feet, burning becomes increasingly difficult because the oil cannot be contained in a boom and because it would rapidly emulsify due to wave action (Allen 1993).

Current

The same limitations that apply to ordinary booms apply to fire-proof booms. When the current is stronger than about one knot the boom cannot contain the oil, which splashes above the boom or escapes beneath it.

Emulsification

Emulsification occurs when crude oil spilled on the water takes in microscopic droplets of water. This usually requires mixing energy in the form of waves. When oil emulsifies its viscosity greatly increases, the total volume of "oily material" increases and most significantly for in-situ burning, ignition and combustion of the spilled oil become increasingly difficult. Water-in-oil emulsion of over 50% will preclude in-situ burning of even light crudes or refined products, while much less than that is required for heavier crudes. It is interesting to note that experiments with emulsion breakers applied to and mixed into the oil enable a mixture of 60% water in oil emulsion to ignite and burn in a fairly normal fashion (Buist, 1995).

Operational

Boom

The present open-water in-situ burning technique requires a fire-resistant boom. This boom needs to withstand the combined forces of heat exceeding 2,000˚F, wave action, and towing. The most prevalent boom is made of ceramic fireproof fabric; other booms are made of stainless steel material. Tests and real burns have shown that further improvements are needed in order to make fireproof booms viable for several consecutive burns. A program to test new booms and improve existing ones is underway (Walton 1997).

Booms are stockpiled in different locations around the nation where in-situ burning has been incorporated as a spill response technique. However, lack or insufficient amount of fireproof boom will limit or prevent the execution of open-water in-situ burning.

Human health

Human health has been one of the major concerns regarding in-situ burning. Essentially, in-situ burning converts the oil from a slick on the water into airborne gases and particulates that may travel long distances and potentially come in contact with people. To prevent possible human health impact, policies and guidelines have been established to limit in-situ burning to condition that will not risk the general population.

Natural resources

In general, any action that limits the spread of the spilled oil or treats it in-situ is seen as beneficial to wildlife and other natural resources. However, there may be situations in which in-situ burning may threaten natural resources. In-situ burning policies adopted by regions around the US incorporate provisions for protection of natural resources when conducting in-situ burning.

Approval

In-situ burning has a narrow window of opportunity. Approval for burning should be given either ahead of time (preapproval) or quickly on a case-by-case basis. If the approval process takes longer than it takes to prepare for the burn, the opportunity for using in-situ burning may be lost.

Emissions from in-situ burning

Studies of the emissions from in-situ burning have shown fairly consistent results. About 85 to 95% of the burned oil becomes carbon dioxide and water, 5 to 15% of the oil is not burned efficiently and is converted to particulates, mostly soot, and the rest, 1-3%, is comprised of nitrogen dioxide, sulfur dioxide, carbon monoxide, polynuclear aromatic hydrocarbons (PAH), ketones, aldehydes, and other combustion by-products (Ferek 1997). No "exotic" chemicals are formed. Rather, the burning of oil on water seems to be similar to burning the oil in a furnace or a car, with the exception that the burn is oxygen-starved and not very efficient, so that it generates ample amount of black soot particulates that absorb sunlight and create the black smoke.

Past burns

Many in-situ burns of oil were conducted over the years or occurred accidentally, in different types of environments. Most of them were successful in removing part or most of the spilled oil. A few examples are given below:

Burmah Agate

In November 1979, the tanker *Burmah Agate* carrying 14 million gallons of crude oil collided with a freighter near Galveston, Texas. The oil ignited and burned for more than a week, creating a large smoke plume. It is estimated that about 75% of the oil burned (Buist 1994).

Exxon Valdez

In March 1989 the tanker *Exxon Valdez* ran aground on Blight Reef in Prince William Sound, Alaska, spilling approximately 11 million gallons of North Slope crude oil. On the second day of the spill, in calm weather, between 15,000 and 30,000 gallons of the oil was collected and burned, using 150 meters of fireproof boom towed by two boats. This successful burn using a fireproof boom boosted the efforts to incorporate in-situ burning as a spill response method.

Kuwait

By far the largest in-situ burning to date occurred in 1991 in Kuwait, when the retreating Iraqi forces set ablaze about 700 oil wells. At the height of this environmental disaster, about 6 million barrels of oil were burned daily (Ferek 1997). It is estimated that more than a billion barrels of oil were burned over nine months until the fires were extinguished. The fires created a massive smoke plume that darkened the sky in the area for many months. When the flames subsided, it became apparent that the massive fires greatly reduced the amount of oil that actually spilled and polluted both the landscape and the marine environment, and that the long-lasting effects of the smoke plume were minimal.

San Jacinto River

Following massive floods, four pipelines containing gasoline, diesel fuel, light crude oil, and liquefied petroleum gas ruptured over the San Jacinto River near Houston in October 1994 and caught fire. The fire lasted for several days. When the floods subsided, a boom was anchored across part of the river to collect the oil escaping from the fire. The oil was ignited and burned in the boom for about 12 hours. Both the accidental and deliberate burning significantly reduced the extent of environmental impact (NTSB 1996).

Marsh burns

In recent years, in-situ burning has been conducted on land more often than on open water. In April 1993, spilled jet fuel was ignited in an ice covered marsh near Brunswick Air Force Base in Maine. After mechanical removal reached the limit of its efficiency, about 30,000 gallons remained in the marsh, and were almost completely burned. Pipeline spills were ignited both in Texas, near Copano Bay in January 1992 and at the Rockefeller Nature Refuge in Louisiana in March 1995. In both cases most of the oil was burned. Studies are being conducted to assess marsh recovery.

Human health concerns

One of the main objections for conducting in-situ burning was based on the concern that the smoke generated could affect the health of the general public downwind of the burn. The health and safety of the responders conducting the burn was also a consideration.

Responders

Safety hazards for in-situ burning operations are similar to those of ordinary skimming at sea, with the added hazards related to the combustion process. Several points are especially useful to keep in mind:

- A specific burn plan should be prepared in order to methodically address safety hazards, protection measures, training requirements, communication, and other operational elements that have to be considered for a successful and safe burning operation. A burn site safety plan should be included in the general burn plan.
- The burning should be controlled, and flashback to the source prevented. Great care must be taken so that the fire is controlled at all times.
- Ignition of the oil slick, especially by aerial ignition methods (such as the helitorch), must be well coordinated with neighboring vessels and be carefully executed. Proper safety distances should be kept at all times.
- In-situ burning at sea will involve several vessels working relatively close to each other, perhaps at night or in other poor-visibility conditions. Such conditions are hazardous by nature and require a great degree of practice, competence, and coordination.
- Response personnel must receive the appropriate safety training. Training should include proper use of personal protective equipment, respirator training and fit-testing, heat stress considerations, first aid, small boat safety, and any training required to better prepare them to perform their job safely.

Safety hazards are substantial and should be given due attention. Usually they pose a much greater risk to the responders than chemical exposure.

General public

In-situ burning generates mostly carbon dioxide and water, particulates, and small quantities of nitrogen oxides, sulfur dioxide, ketones, aldehyde, and other minor combustion gases. PAHs, some of which are suspected human carcinogens, are found in minute concentrations, adsorbed to the soot particulates. Studies on in-situ burning smoke components indicate that particulates in the smoke plume remain the only agent of concern more than a mile or two downwind. The gases created in the burn dissipate to background levels a short distance downwind, and the level of PAHs attached to the particulates is much below the level of concern (Fingas 1994). Public exposure to smoke particulates from the burn is not expected unless the smoke plume sinks to ground level. However, since the general public may include individuals sensitive to air pollutants their tolerance to particulates may be significantly lower than that of the responders.

Particulate size

Since 10 micrometers (µm) in diameter is the size below which particulates may be inhaled and become a burden on the respiratory system, scientists divide the particulate mass into "total" particulates, which include any size measurable, and "PM-10," which is the fraction of particulates smaller than 10 µm 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. If those particulates do not descend to ground level (where people are), they will not threaten the population downwind.

Particulate level of concern

The general public may be protected by minimizing exposure and conducting the burn only when conditions are favorable and exposure to particulates from the burn is below the level of concern. The National Response Team-recommended level of concern for the general public is 150 micrograms of particulates per one cubic meter of air, over a one hour period (NRT 1995). This level is much more conservative than the present legal requirement set at 150 microgram of particulates in a cubic meter of air, but averaged over 24 hours. In the process of adopting in-situ burning, the different regions around the country adopted the NRT's recommendation for a health-protective particulate level of concern.

Monitoring and modeling the smoke plume

The easiest and simplest way to monitor the smoke plume is by visual observation, which provides useful information on the plume direction and behavior. However, to try and assess the smoke component in the plume, instruments tethered from a blimp collected data on gases and particulate composition and concentration, while remote controlled helicopters took samples in the smoke, and a Light Detection and Ranging (LIDAR) instrument, which uses laser beams to detect particulate concentration in the plume was used from an aircraft in several test burns (Fingas 1994). These methods were very useful in providing information on the smoke composition and component concentrations, but they can't be used on a real-time basis to provide immediate feedback during the burn itself.

Real-time aerosol monitors are now available. They are small and portable, may be carried by hand and in a helicopter, and are easy to operate. Since they count particles by light scattering, their output is not as accurate as more traditional methods that weigh the particulates as they accumulate on a filter media. However, these instruments may provide useful real-time feedback during in-situ burning operations if population exposure to the smoke plume becomes an issue.

Modeling is another approach to estimating the concentration of particulates in the plume. Several models were developed, including a relatively simple model developed by NOAA, and ALOFT, a complicated model developed by the National Institute of Standards and Technology. Using information available on atmospheric conditions, burn parameters, and even terrain characteristics, this model, which is now available for use on a powerful PC, can predict the plume behavior and both ground and plume particulate concentrations over distance. The model has been used for several test burns, and was found to be reasonably accurate. Models are particularly useful for planning purposes and for situations in which direct air sampling is not possible.

Environmental Concerns

Burn residue

Generally, the composition of burn residue is similar to that of the original oil. The difference is that the residues have less volatile hydrocarbons with low boiling points, and are denser and more viscous than unburned oil.
Experience has shown that the burn residues may either float or sink. In a controlled test burn during the *Exxon Valdez* spill, an estimated 15,000 to 30,000 gallons of Prudhoe Bay crude oil were burned. Following this burn, about 300 gallons of “stiff, taffy-like burn residue that could be picked up easily” remained (Allen 1990).

During the 1991 explosion and burning of the tanker *Haven* off Genoa, Italy, burn residues sank. 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. Moller (1992) reported that several 1991 surveys confirmed that there was sunken oil offshore and along the coast.

In other cases, the residues stay afloat while warm, but sink as they cool off. In a series of test burns in Prudhoe Bay, Alaska using Alaska North Slope crude, it was found that, as the residues cooled, some of it sank (Buist 1995). The sunken residues formed a brittle solid, while the residues that stayed afloat were semi-solid tar. It seems, therefore, that prompt collection of the residues can at least in some cases prevent the residues from sinking.

Direct temperature effect

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 in the water during the Newfoundland test burn showed no increase in water temperatures during the burn (Fingas 1994). It appears that the burning layer may not remain over a given water surface long enough to change the temperature because the ambient-temperature seawater is continually being supplied below the oil layer as the boom is towed.

Water-column toxicity

Environment Canada coordinated a series of studies to determine whether in-situ burning caused 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 (Daykin 1994).

Results from the laboratory and field studies indicated that, although toxicity increased in water samples collected beneath oil burning on water, this increase was generally no greater than that caused by the presence of an unburned oil slick on water. Chemical analyses performed along with the biological tests reflected low hydrocarbon levels in the water samples.

Effect on 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. The microlayer, often considered to be the upper millimeter or less of the water surface, is habitat for many sensitive life stages of marine organisms, including eggs and larval stages of fish and crustaceans, and reproductive stages of other plants and animals. It is known that cod, sole, flounder, hake, anchovy, crab, and lobster have egg or larval stages that develop in this layer.

There is little doubt that in-situ burning would kill the organism in the area of the burn. However, when considering the small area affected by in-situ burning, the rare nature of this event, and the rapid renewal of the surface microlayer from adjacent areas, the long-term biomass loss is negligent (Shigenaka 1993).

Birds and mammals

In the wake of a major oil spill, any spill response method that would prevent the oil from spreading and impacting large areas is clearly advantageous for birds and mammals. During the *Exxon Valdez* spill thousands of birds were killed by the oil spreading hundreds of miles away from its source. Based upon our limited experience, birds and mammals are more capable of handling the risk of a local fire and temporary smoke plume than of handling the risk posed by a spreading oil slick. Birds flying in the plume can become disoriented and could suffer toxic effects. This risk, however, is minimal when compared to oil coating and ingestion, the result of birds' exposure to the oil slick.

The effect of in-situ burning on mammals is yet to be seen. It is not likely that sea mammals will be attracted to the fire, and the effect of smoke on marine mammals is likely to be minimal. Mammals, on the other hand, are adversely affected by oil ingestion and oil coating of their fur. Therefore, reducing the spill size by burning the spilled oil can reduce the overall hazard to mammals.

Once coated by oil, neither birds nor mammals have responded well to rehabilitation efforts, and although much has been learned and rehabilitation methods have greatly improved, the success rate of wildlife rehabilitation has been moderate at best.

Burning vs. Evaporation

Leaving the oil untreated has a deleterious effect on air quality. Spilled oil left untreated would evaporate at a rate that depends upon the type of oil, time elapsed from release, wind, waves, and water and air temperatures. The amount evaporated is substantial. The ADIOS oil behavior model developed by NOAA predicts that 33% of spilled Alberta Sweet crude would evaporate after 24 hours in 70˚F water and 10 knot wind, and after five days 43% would have evaporated. This evaporation pattern, similar in other oil types, emphasizes the need for quick action if in-situ burning is selected as the response tool.

The decision of whether to burn involves a tradeoff: burning the oil would reduce or eliminate the environmental impact of the oil slick and convert most of the oil to carbon dioxide and water. Burning, however, would generate particulates and cause air pollution. Not burning the oil would enable the slick to spread over a large area and affect the environment. Particulates would not be produced, but up to 50% of the oil would evaporate, causing a different kind of air pollution.

Waste generation

Review of the environmental impacts would not be complete without considering the waste an oil spill can potentially generate. It was estimated that 350 miles of sorbent boom was used during the first summer of the *Exxon Valdez* cleanup (Ferriere 1993), more than 25,000 tons of sorbent material of all kinds was sent to landfills, and oily water twice the volume of the oil spilled (from skimming a fraction of the oil) had to be treated (Fahys 1990). Enough energy was used that summer to support the energy needs of 11,000 people, power 1,300 boats of all sizes, and provide hot water equal to the needs of a city of 500,000 people (Ferriere 1993).

In-situ burning of oil is going to generate waste. Even the most efficient burning will leave a taffy-like residue that will have to be collected and treated or disposed of. Burning the oil at sea will not be as efficient as burning it in engines, furnaces, or power plants, and will generate a substantial amount of particulates. However, by minimizing the solid and liquid waste generated by beach cleanup, and by reducing the energy required to support the response operation, burning even some of the oil at sea is likely to reduce the overall waste generation of a spill.

Summary

Like any spill response method, in-situ burning can offer important advantages over other response methods in specific cases, and may not be advisable in others, depending upon the overall mix of circumstances.

Pros:

- In-situ burning can potentially remove large quantities of oil from the surface of the water with a relatively minimal investment of equipment and manpower.

- Burning may offer the only realistic means of spill response where logistics and environmental conditions preclude other options, such as spills in ice-covered water.

- In-situ burning may prevent or significantly reduce the extent of shoreline impacts, including exposure of sensitive natural, recreational, and commercial resources.

- Burning rapidly removes oil from the environment, particularly when compared to shoreline cleanup activities that may take months or even years.

- In-situ burning reduces storage and disposal requirements by converting the oil to gases and particulates that naturally disperse in the atmosphere. Residues left at the end of the burn need to be collected and disposed of, but they represent a small fraction of the initial oil volume.

- In-situ burning is versatile. It may be conducted on open water, ice-covered water, on rivers, on wetlands and marshes, and on dry land.

Cons:

- The method generates large quantities of highly visible smoke that may adversely affect human population downwind.
- In-situ burning pose risks to response personnel, and requires training, communication, and coordination.
- Burn residues may sink and affect natural resources. The longer-term effects of burn residues on exposed populations of marine organisms have not been investigated. It is not known whether these materials would be significantly toxic in the long run
- In-situ burning can be done only over a short period of time following a spill. It requires fast action and response. Furthermore, in-situ burning can be done only in relatively calm weather.
- As of this writing, all the booms currently tested have suffered from flaws. A sturdy, long lasting, effective, and relatively inexpensive fireproof boom is not yet available.

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RRT VI Guidelines for Inshore/Nearshore In-Situ Burn

Introduction:

In-situ burning is being considered with growing interest as a response tool for oiled coastal wetlands. Burning of wetland grasses has been practiced as a vegetation management technique for many years, but burning of oiled wetlands is relatively new. Deciding how to respond to an oiled coastal wetland is a complex issue for which there can be no single answer. In keeping with the pro-active nature of RRT VI, the following guidelines and checklist for quick approval of an in-situ coastal wetland burn are provided.

Environmental Considerations:

It must be determined if cleanup is necessary or desirable. A consultation with a biologist, botanist or ecologist would be extremely helpful in assessing options. Cleanup in a wetland appears to be justified when oil can be removed with minimum impact, when other natural resources (such as migrating birds) are at high risk of being oiled, or when unassisted recovery is likely to be very slow.

Natural (unassisted) recovery may be the best option to follow when:

- Oiling is light and natural recovery is likely to occur in an acceptably shorter time frame
- Cleanup activities would detrimentally impact the wetland
- Wildlife are at low risk of being oiled.

In-situ burning as a spill response method may provide a means to remove the oil from the impacted area without resorting to mechanical cleanup methods, which may be destructive or impossible to carry out. In-situ burning may minimize both short term risks of further impact of the spilled oil, and long term risks of persistant toxicity to Marsh plants and biota.

In-situ burning has advantages and disadvantages. The following pros and cons should be examined when considering the in-situ burning option for oiled wetlands:

Pros

- Minimizes physical damage: Where access is limited or mechanical/manual removal has the potential to cause unacceptable levels of impact by equipment mobilization and trampling, burning can rapidly remove oil from sensitive areas.
- Provides an option when other options fail: It provides a response option when no other options are acceptable or feasible, or where oil residues will be unacceptably high with other options, including natural recovery.
- Removes oil quickly: 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 (e.g., rain or flooding), or a seasonal increase in wildlife use, such as arrival of large numbers of migratory waterfowl.

Cons

- Plant damage: Burning can cause substantial initial plant damage because the above-ground/water vegetation is removed.
- Long term impact: Burning can cause long-term impacts to vegetation, when the fire is so hot or water level is too low, that the below-ground plant parts are killed.
- Oil penetration: There is a potential for burning to increase oil penetration into the substrate, when there is no standing water.
- Damage to biota: Any animals present and unable to escape (such as gastropods on clean vegetation above the oiled area) will be killed.
- Residues: Heavy fuel oils, when burned, may produce residues that are difficult to remove.

Resource managers have been conducting 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 to restore habitats in areas that are historically dependent on frequent wildfires to sustain these ecosystems. The presence of oil in a wetland may have two important effects: the high BTU of the oil may increase the temperature and heat penetration of the burn, and oil residue may remain after the burn 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. Based on discussions with refuge staff with fire management duties, the following guidelines were developed for specific types of non-oiled wetland habitats:

Wooded Swamps (guidelines are from the southeast, Okefenokee Swamp)

- Burns in winter tend to cause less damage in terms of species mortality and diversity; only a loss of fuel occurs.
- Burns in later summer result in higher mortality to the larger plants and hardwoods probably because they are more susceptible to stress, and the soil conditions are drier, leading to higher acute mortality from heat.
- Spring and summer burns are more likely to cause changes in species composition; species that are promoted by burning tend to grow vigorously after the burn, out-competing the less fire-tolerant species.
- Moisture levels are extremely important. Although high moisture levels make starting the burn more difficult, these conditions are less likely to cause high plant mortality or a change in species composition.
- Greater damage to vegetation results from burns during dry seasons, when the fire is more likely to burn deeper into organic soils and cause higher damage to roots. When the soils are wet, only the above ground vegetation is burned off.

Fresh-to-Brackish Impoundment Marshes (data are from Merritt Island NWR)

- Prescribed burns should be scheduled for periods when they occur naturally, namely in the dry/lightning season.
- *Juncus* is killed if flooded after a burn.
- *Spartina bakeri* burns well, readily, and during most times of the year, even in standing water.

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

- Make sure that it is possible to contain and control the fire; it is not as easy to put out a fire in vegetated wetland as it is with oil contained in a fireproof boom.

- Impacts to below ground vegetation are likely to be less if a water layer exists between the oil and the substrate.
- A standing water layer of just a few inches may get hot enough to kill the roots anyway. Little information on this relationship has been compiled and this type of data may be collectable during monitoring efforts.
- Burning of oiled woody wetland vegetation (compared to herbaceous vegatation) should not be considered.
- 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 prior to new plant growth seems to be the best time.
- If it can be done with minimal impacts, heavy accumulations of oil should be removed by other methods in order to reduce the amount of burn residues and burn duration which may cause long-term impacts to both vegetation and animals returning to the habitat.
- Light fuel oils and crudes burn more efficiently and generate less residues, which should reduce the potential for long-term impacts.
- There is some concern that burning of muddy substrates could alter their physical properties (i.e., make them hard) thus degrading their biological productivity.
- Every wetland is different in terms of the wetland type, plant species composition, environmental parameters, and the known or estimated tolerances of that type of system to physical and chemical disturbances. Biologists, botanists or ecologists should be consulted prior to the use of burning as a response technique in a wetland.

Little data is found on the burning of oiled wetlands. The NOAA Scientific Support Coordinator may be able to coordinate with ongoing (funded) research to address site specific monitoring needs.

Safety Considerations

Because of the intense heat, the smoke plume usually rises several hundreds to several thousands of feet. It then levels off and is blown by the wind in a narrow, and often meandering band while dissipating. After that it moves about according to weather conditions at the time. Some parts of the plume occasionally dip back down toward the surface but the majority of the smoke usually stays well up in the air. If the wind is blowing away from a populated area it is conceivable that a burn could be conducted immediately adjacent to the area. However, if the wind is blowing toward a populated area there must be reasonable assurances that people will not be exposed to excessive concentrations of pollutants.

Concentrations of small particulates in the smoke plume dissipate and are generally within the standard 150 micrograms per cubic meter of air, averaged over 24 hours, within one to three miles from the burn. In most cases, three miles from populated areas is considered to be a reasonably safe distance in case the plume dips down to land.

At night, wind conditions are usually more stable. Burning may be done under stable wind conditions, however, data on the inversion layer should be known. Optimal wind conditions are 5-10 knots preferably not exceeding 20 knots. Burning may be done with winds exceeding 20 knots, however the lofting effect will be reduced, and the smoke may hug the ground. This condition is acceptable if the plume is not expected over a population center. The risk that in-situ burning may pose to the general public located downwind should be considered before any burning is initiated. If the risk is deemed unacceptable in-situ burning should not be done.

Burning must be safe and practical in light of spill status and spill source stabilization. Make sure burning is compatible with mechanical cleanup operations.

It is assumed that the responsible party has implemented a site safety work plan with a section specifically addressing in-situ burning. Personnel conducting the burn should be trained, provided with the necessary protective equipment, and monitored as needed.

Operational Considerations

The type and condition of the oil must be sufficiently combustible. Very heavy or weathered oils may not support combustion. Some type of wicking agent might be necessary.

State/local air quality regulations for burning must be followed and the appropriate agency contacted. Burning may be restricted between 9:00am to 5:00pm. It is also recommended to call the FAA with proposed burn times and locations.

Oil Spill Response Checklist for Coastal Wetland In-Situ Burn

The following checklist is provided as a summary of important information to be considered by the Federal On-Scene Coordinator (FOSC) in reviewing any request to conduct in-situ burning in a coastal wetland. It may be completed by the Responsible Party with input from resource managers and/or SSC. If the Burn is recommended by the Responsible Party and the State and approved by the FOSC, the checklist may be faxed to the RRT (DOI, DOC, EPA and State) for immediate consideration.

Name of Incident:

Date and Time of Incident:
Name of Product Spilled (specific gravity, API or MSDS attached if available):
Total Volume of Oil Spilled:
Total Volume of Oil to be Burned:
Oil Thickness Over Water:
Wetland Type (e.g. salt marsh) and dominant Plant Species:

Description of Incident:

Description and size of Area to be Burned (include location of proposed burn with respect to spill source, an attached sketch, survey or picture of area would be helpful):

Environmental Concerns and Recommendations, (include environmental trade-offs, water depth in marsh, past management practices, possible impending weather, presence of wildlife, alternate or additional clean-up methods):

Local Air Quality Personnel Notified (name and number):

Land Owner Notified (name and number):

Distance to Nearest Population Center:

Environmental Review Personnel (name and number):

Site Safety Plan Reviewed:

Present and Forecasted Weather:

Status of Spill Source:

Description of Operations (include how the fire will be contained, controlled and ignited):

Method to Recover Burn Residue:

Monitoring to be Performed:

Signatures: ______________________________
Federal On Scene Coordinator

____
Responsible Party

____
State Representative

Other

In-Situ Burn Unified Command Decision Verification Checklist

Purpose and Summary:

The following checklist, created with input from the Region II RRT, provides a summary of important information to be considered by the Unified Command, consisting of the federal On-Scene Coordinator (OSC), 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 of Region II. The document is intended to allow Unified Command verification of a decision, rather than an information distribution sheet or an approval form.

Each section of the checklist provides a series of "limiting factors" questions for each of the decision points on the Region II In-Situ Burning Decision Flowchart. 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: ______________________

Under Region II MOU, additional consultation or concurrence is required in Zone C (or Zone B if winds are not from the pre-approved directions).

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: ____________	____________	____________	____________

FIELDS MAY BE LEFT BLANK, LIMITING FACTORS DO NOT PRECLUDE BURNING. PLEASE REFER TO DOCUMENT SUMMARY AND PURPOSE.

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 – 6 miles offshore:	FOSC approval of burn?			
Zone B – 3 to 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 concur with burn?			
	State(s) RRT representative concur with burn?			
	Consultation with DOI RRT representative?			
	Consultation with NOAA RRT representative?			
	Region I/III consultation/concurrence if burn to impact neighboring Region?			
Notifications planned as described in MOU (EPA, DOI, NOAA, State(s))?				
Attachments/Additional Information:				

FIELDS MAY BE LEFT BLANK, LIMITING FACTORS DO NOT PRECLUDE BURNING. PLEASE REFER TO DOCUMENT SUMMARY AND PURPOSE.

To be completed by Scientific Support Team:

Oil Burnability	Optimal Condition Yes or Probable	Sub-Optimal Condition No or Unlikely	Comments
Anticipate oil to remain ignitable (fresh, not highly emulsified)?			
Attachments/Additional Information:			

To be completed by Scientific Support Team:

Weather/Sea Conditions	Optimal Condition Yes or Probable	Sub-Optimal Condition No or 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 feet?			
Attachments/Additional Information:			

To be completed by Requesting Party:

Operational feasibility	Optimal Condition Yes or Probable	Sub-Optimal Condition No or 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:			

FIELDS MAY BE LEFT BLANK, LIMITING FACTORS DO NOT PRECLUDE BURNING. PLEASE REFER TO DOCUMENT SUMMARY AND PURPOSE.

To be completed by OSC/SOSC staff in consultation with meteorologists/modelers as appropriate:

Human and Environmental Impacts	Optimal Condition Yes or Probable	Sub-Optimal Condition No or 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**)			
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: ____

FIELDS MAY BE LEFT BLANK, LIMITING FACTORS DO NOT PRECLUDE BURNING. PLEASE REFER TO DOCUMENT SUMMARY AND PURPOSE.

Health and Safety Aspects of In-situ Burning of Oil

Nir Barnea
National Oceanic and Atmospheric Administration
Seattle, WA 98115 USA

BACKGROUND

In-situ burning is the combustion of a spill product at the site of the spill (in situ is Latin for "in place".) In-situ burning of oil may offer a logistically simple, rapid, inexpensive, and relatively safe means for reducing the net environmental impact of an oil spill. 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.

Required Conditions

To burn oil on water, four major conditions must be met:

1. The oil layer has to be thick enough to support combustion. Oil layers thinner than 1 to 2 mm lose too much heat to the water and cannot support combustion.

2. The ignition devices used must be hot enough and last long enough to ignite the oil.

3. The water-in-oil emulsion may not contain more than 30 to 50 percent water to ignite and support combustion.

4. To use currently available fire resistant booms, environmental conditions must be favorable: wind speed should be below 20 knots, and wave height should be below three feet.

Burning Technique

An in-situ burning technique likely to be used would employ towing boats and fire-resistant booms to contain the spilled oil and keep it from spreading. The boom, attached to the boats by towing lines, would be pulled by the boats to form a U shape. The open end of the U is maneuvered through the oil slick, and a "boomful" 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 so that it slowly advances ahead of the current to ensure that the oil is concentrated at the back end of the boom and maintains maximum thickness. After the oil is burned, the process may be repeated for as long as in-situ burning is feasible.

Burning Efficiency

In-situ burning has been studied under controlled conditions in laboratories and in field tests, and recently under realistic conditions in an experiment off the coast of Newfoundland, Canada. This experience indicated that in-situ burning can be an effective oil-removing technique, removing 50 to 99 percent of the oil collected in the boom. In addition, a field "real" burn conducted in the first days of the *Exxon Valdez* spill in Prince William Sound, Alaska, resulted in the burning of 15,000 to 30,000 gallons of Prudhoe Bay crude oil at an estimated efficiency of 98 percent or better (Allen 1990).

Plume Behavior

The heat generated by the burning oil in the boom (1800 °F were measured at the top of the boom at the Newfoundland burn) will cause the smoke to rise several hundred to several thousand feet, and at the same time be carried away by the prevailing winds. In areas having well-developed sea-breeze systems, plume fumigation and recycling may draw the smoke toward the surface. It is expected that the plume will be high enough to stay out of the sea-breeze/land-breeze circulation cell. The smoke plume at the in-situ burning conducted off Newfoundland and at marsh and brush burns leveled off at several hundred feet, and then lofted slowly over distance. The upper boundary of the plume often extends to an altitude of several thousand feet. The main plume may also split into two or more smaller plumes, each heading in a somewhat different direction.

HUMAN HEALTH CONSIDERATIONS

The possible health hazards of in-situ burning to nearby response personnel conducting the burn will be different from those for the general public at a substantial distance away.

<u>Response personnel:</u> Response personnel working close to the burn may be exposed to levels of gases and particulates that would require them to use personal protective equipment. They should receive the training required to conduct the operation safely. Monitoring of the responders' work environment should be conducted as needed. Occupational standards such as OSHA's Permissible Exposure Limits (PEL) are applicable to this group of typically healthy adults.

<u>General public:</u> Based on data from the Newfoundland Offshore Burn Experiment (NOBE) (Ferek 1994; Fingas et al. 1994; Bowes 1994) and previous burns (Fingas et al. 1993; Booher 1992; Evans et al. 1992), particulate concentrations in the smoke plume remain the only agent of concern past a mile or two downwind, the gases created in the burn having dissipated to levels close to background. Public exposure to smoke particulate from the burn is not expected to occur unless the smoke plume goes down to ground level. Since the general public may include sensitive individuals such as the very young and very old, pregnant women and people with pulmonary or cardiovascular diseases, this population's tolerance to particulates may be significantly lower than that of the responders. Protecting the general public may be achieved by minimizing exposure and conducting the burn only when conditions are favorable and exposure to particulates from the burn is below the level of concern. There is little data concerning the effect of particulates from in-situ burning of oil on humans. Based on chemical analysis of soot particulates and their physical behavior, the hazard is expected to be similar to that of better known particulates emissions now regulated by the National Ambient Air Quality Standard (NAAQS).

Determining the level of concern for exposure to particulates is not simple. The existing NAAQS of 50 $\mu g/m^3$ annual mean and 150 $\mu g/m^3$ averaged over 24 hours is designed for continuous sources such as industry and motor vehicle emissions. In-situ burning is likely to occur over a short period of time: hours, perhaps a day or two. Is the existing PM-10 standard well suited for in-situ burning? This issue definitely warrants further consideration.

Toxic Components of the Smoke Plume

The smoke emitted from oil combustion contains gases and particulates that may have toxic effects on our bodies, much like exhaust emissions from motor vehicles or smoke from wood stoves. The health risk will depend on the actual exposure to these agents.

Most of the oil in in-situ burning will be converted to carbon dioxide and water. Particulates, mostly soot, comprise ten to fifteen 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 by-products are discussed below, and their NAAQS and occupational exposure limits are shown in Table 1.

Sulfur dioxide (SO_2) is a gas formed when sulfur in the oil or hydrogen sulfide coming out of a well oxidize 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 SO_2 in the smoke plume depends on the sulfur content of the oil. Average SO_2 levels measured in experimental burns have been below 2 ppm in the plume 100-200 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 limits.

Pollutant	OSHA PEL*	ACGIH TLV*	NAAQS
SO_2	5 ppm	2 ppm [5 ppm]	0.14 ppm averaged over 24 hours, 0.03 ppm annual arithmetic mean
NO_2	5 ppm	3 ppm [5 ppm]	0.05 ppm annual mean
PAH	0.2 mg/m^3 (volatile)	0.2 mg/m^3 (volatile)	---
CO	50 ppm	25 ppm	35 ppm over one hour, 9 ppm over 8 hours
Particulates	5 mg/m^3 for particulates $\leq$ 3.5 μm	10 mg/m^3 for total dust (new standard in progress)	PM-10: 0.15 mg/m^3 over 24 hr., 0.05 mg/m^3 annual mean

* Time-weighted average concentration over 8 hours. Short-term exposure limits are shown in square brackets.

Nitrogen dioxide (NO_2) is another gaseous by-product of oil combustion. Like SO_2, it is reactive, toxic, and a strong irritant to the eyes and respiratory tract. NO_2 is less soluble than SO_2 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 (Ferek 1994). Therefore, it is not expected to pose a threat to the general public several miles downwind of the burn.

Polynuclear aromatic hydrocarbons (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 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 (Fingas et al. 1994).

PAHs were found in barely detectable concentrations in the smoke from the Kuwaiti oil fires (Campagna and Humphrey 1992). Low levels of PAHs were also detected in experimental oil burns, (Mass Selective Detector, analytical sensitivity 0.01 $\mu g/m^3$ air) with levels in the plume less than 0.01 ppm (Fingas et al. 1994). Considering the low level of PAHs detected so far, it is felt that they present only a small exposure hazard.

Carbon monoxide (CO) is a common by-product 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 (Fingas et al. 1993).

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 particulates 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 (μm) in diameter is the size below which particulates may be inhaled and become a burden on the respiratory system, scientists divide the particulate mass into “total” particulates, which include any size measurable, and “PM-10,” which is the fraction of particulates smaller than 10 μm in diameter. The combined effect of the anatomical structure of the respiratory system and physical behavior of particles cause particles greater than 10 μm in diameter to be deposited and removed from the air stream at the nose and upper portion of the respiratory tract. Particles 5 to 10 μm in diameter would be deposited along the elaborate air conducting tube system, the bronchi. Only particles smaller than 5 μm will actually be deposited in the deeper portion of the lungs, in the alveoli, which are the little sacs where gas exchange takes place. The median size of the particulates reaching the alveoli is approximately 0.5 μm in diameter, meaning that half the number of particulates will be smaller than 0.5 μm, and half will be larger. Only 2 percent of the particulates found in the alveoli would be larger than 3 μm (Wright 1978).

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 problem 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 cites in the United States: Philadelphia; Detroit; Provo, Utah; and Birmingham, Alabama. Higher levels of PM-10 were associated with an increase in daily morbidity and mortality, especially among older people and people with allergies, respiratory problems, or cardiovascular diseases. An increase of 100 $\mu g/m^3$ of the measured daily particulate level was associated with six 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 population 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 participants 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. The general trend showed variable concentration of PM-10 in the smoke plume. While at several spots the concentration of particulates exceeded 150 $\mu g/m^3$ even 10 miles downwind of the burn, other places in the plume had particulate concentrations lower than 150 $\mu g/m^3$. The most remarkable finding is that PM-10 concentration beneath the plume, 150-200 feet above the surface, did not exceed background levels of 30 to 40 $\mu g/m^3$ (Ferek personal communication 1994). These data agree well with previous measurements done in test burns in Mobile Bay, Alabama.

Safety Hazards

Safety hazards for in-situ burning operations should be similar to those of ordinary skimming at sea, with the added hazards related to the combustion process:

1. In-situ burning is a process that involves the intentional setting of a fire. Great care must be taken so that this fire is controlled at all times.

2. Ignition of the oil slick, especially by aerial ignition methods (such as the helitorch), must be well coordinated with neighboring vessels and be carefully executed. Weather and water conditions should be kept in mind, and proper safety distances should be kept at all times.

3. In-situ burning at sea will involve several vessels working relatively close to each other, perhaps at night or in other poor-visibility conditions. Such conditions are hazardous by nature and require a great degree of practice, competence, and coordination.

4. Response personnel must receive the appropriate safety training. Training should include proper use of personal protective equipment, respirator training and fit testing, heat stress considerations, first aid, small boat safety, and any training required to better prepare them to perform their job safely.

Safety hazards are substantial and should be given due attention. Usually they pose a much greater risk to the responders than the previously discussed chemical exposure.

In-situ burning will require only a fraction of the people needed to clean the same amount of oil if it impacts the beaches. In addition, personnel conducting the burn are expected to be well trained and monitored and, hopefully, have a low accident rate. In-situ burning, by minimizing the amounts of oil impacting the beaches, may prevent the illnesses and injuries that are often associated with beach cleanup operations.

ENVIRONMENTAL CONSIDERATIONS

While the main purpose of this brief review is to present the major human health and safety considerations of in-situ burning, mentioning the greater health aspects that affect our environment and, ultimately, our quality of life is definitely warranted. We will touch on a few points only. These points include the feasibility of burning the oil as opposed to leaving it to evaporate, waste generation, and possible effects on exposed wildlife.

Burning vs. Evaporation

A point to keep in mind is that leaving the oil in place will have a deleterious effect on air quality. Spilled oil left untreated would evaporate at a rate that depends on the type of oil, time elapsed from release, wind, waves, and water and air temperatures. The amount evaporated is substantial. For example, 32 percent of spilled Alberta Sweet crude would evaporate after 24 hours in 80 degree water, and after five days 42 percent would have evaporated. This evaporation pattern, similar in other oil types, emphasizes the need for quick action if in-situ burning is selected as the response tool.

The decision whether to burn or not to burn involves a tradeoff: burning the oil would reduce or eliminate the environmental impact of the oil slick and convert most of the oil to carbon dioxide and water. Burning, however, would generate particulates and cause air pollution. Not burning the oil would enable the slick to spread over a large area and impact the environment. Particulates would not be produced, but up to 50 percent of the oil would evaporate, causing a different kind of air pollution.

Waste Generation

Mechanical cleanup of oil spills generates large amounts of waste. It was estimated that 350 miles of sorbent boom was used during the first summer of the Exxon Valdez cleanup (Ferriere 1993), more than 25,000 tons of sorbent material of all kinds was sent to landfills, and oily water twice the amount of the oil spilled (from skimming a fraction of the oil) had to be treated (Fahys 1990). Enough energy was used that summer to support the energy needs of 11,000 people, power 1,300 boats of all sizes, and provide hot water equal to the need of a city of 500,000 people (Ferriere 1993).

In-situ burning of oil is going to generate waste. Even the most efficient burning will leave a taffy-like residue that will have to be collected and treated or disposed of. Burning the oil at sea will not be as efficient as burning it in engines, furnaces, or power plants, and will generate a substantial amount of particulates. However, by minimizing the solid and liquid waste generated by beach cleanup, and by reducing the energy required to support the response operation, burning even some of the oil at sea is likely to reduce the overall waste generation of a spill.

Effects on Birds and Mammals

Based on our limited experience, birds and mammals are more capable of handling the risk of a local fire and temporary smoke plume than of handling the risk posed by a spreading oil slick. Birds flying in the plume can become disoriented, and could suffer toxic effects. This risk, however, is minimal when compared to oil coating and ingestion, the result of birds' exposure to the oil slick.

The effect of in-situ burning on mammals is yet to be seen. It is not likely that sea mammals will be attracted to the fire, and the effect of smoke on marine mammals is likely to be minimal. Mammals, on the other hand, are adversely affected by oil ingestion and oil coating of their fur. Therefore, reducing the spill size by burning the spilled oil can reduce the overall hazard to mammals.

Once coated by oil, neither birds nor mammals have responded well to rehabilitation efforts, and although much has been learned and rehabilitation methods have greatly improved, the success rate of wildlife rehabilitation has been moderate at best.

CONCLUSIONS

In-situ burning of oil may provide an efficient and rapid method of oil spill response, providing that the requirements to carry on the response are met. Burning the oil on the water generates a large amount of smoke, which contains particulates and toxic gases. Among those, particulates seem to be the major agent of concern, as their concentration in the center of the plume remains above the level of concern for the general population for several miles downwind. It was found, however, that particulates concentration under the plume does not significantly exceeds background levels. Protection of response personnel can be achieved by adequate training and personal protective equipment. The general public can be protected by establishing burning guidelines that will prevent the burn from becoming a health hazard to the public.

When compared to conventional response methods and to beach cleanup, in-situ burning can reduce the number of people required to clean the beaches, and reduce the injuries associated with this hazardous work. By eliminating the oil at the source of the spill, contact with oil by marine birds and mammals can be reduced. Burning the oil to minimize beach impact will reduce the waste generated by conventional beach cleanup. While generating substantial amounts of combustion by-products, mostly carbon dioxide, water, and particulates, in-situ burning reduces the amount of VOCs evaporating from the spilled oil.

Since in-situ burning of oil has the potential to reduce the destructive impact of oil spills, and since the risk it poses to the responders and to the population downwind are, under most circumstances, acceptable, it should be one of the response options available to combat future oil spills.

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SAMPLE SITE SAFETY PLAN FOR MARINE IN-SITU BURN OPERATIONS

Introductory Note: Response situations expose personnel, and sometimes the general public, to potentially hazardous situations. In-situ burn (ISB) operations add an additional element to safety considerations. The precautions necessary for the safety of personnel in an ISB response effort must include safety protocols for burning in addition to those for conventional cleanup.

The following site safety plan includes those elements unique to ISB; refer to the general site safety and health plan for spill response safety considerations not related directly to ISB. This plan is designed as an appendix to the umbrella site safety plan for the overall response. The sample is not a standard, but rather a suggested starting point.

The plan contains some operational aspects which may create redundancy with ISB operations plans. If a safety consideration is tied to the specific operation that makes it different due to the added hazard of ISB, then the operation is included in this plan. For regions and responders with comprehensive ISB operations plans, redundancy may be dropped from the sample.

TABLE OF CONTENTS

1 ISB SITE DESCRIPTION[1]

	NO	YES	
A. Geographic Location of Burn Site(s):	NA	NA	
B. Hazards:	G G G G	G G G G	Oil Type: (See General Site Safety Plan) Burn Promoters: (If yes, attach an MSDS) Combustion by-products: (See Section ----) Heat/Flame: (See Section ---)
C. Weather Conditions: (used to determine trajectory of boom sweep and smoke plume)	NA	NA	Wind velocity/direction: Current velocity/direction:
D. Population Centers: (Indicate demographic information -- e.g., urban or rural; residential or industrial)	G	G	1. 2. 3.
E. Sensitive Areas: (e.g., endangered species habitat, commercial fishing activity, vessel traffic lanes, cultural/historical resource)	G	G	1. 2. 3.
F. Secondary Fuels Sources: (e.g., nearby oil storage facility, pipeline, or vegetation)	G	G	1. 2. 3. Establish a safe zone and designate as off limits to burning operations
G. Secondary Sources of Ignition: (e.g., flares)	G	G	1. 2. 3. Establish a safe zone and designate as off limits to burning operations
H. Map: Attachment #___	G G G G G G G G	G G G G G G G G	Direction of response sweep Burn path/trajectory of smoke plume Population centers Sensitive areas Contamination zones Exclusion zones Hazardous zones Other:
I. Medical Emergencies: (ISB-Related)	First Aid :location Hospital Name: Phone: Has the hospital been contacted to verify whether burn and/or smoke inhalation victims can be handled? Doctor:		

[1] Refer to the general site safety plan for entire spill location.

2 BURN OBJECTIVES

All work shall be conducted in accordance with procedures established during pre-burn briefings and attached work plans. A work plan is provided as attachment: _____.

Entry Objectives: Recovery of oil/fuel spill, booming operations, and ISB operations.
Other activities/objectives: ____

____
____
____
____
____

Detailed objectives will be developed daily as part of the overall burn plan described in Section 4.1 of this plan (or refer to the applicable burn operations plan). Daily objectives will be communicated to personnel during the pre-departure safety briefing

3 RESPONSE ORGANIZATION

3.1 **Contact List**: See Annex B.

3.2 **Personnel Responsibilities**: [Positions discussed below may vary depending upon the spill management, expertise of personnel, and limited availability of trained people. If necessary, one person may fulfill more than one role.] The following subsections describe personnel responsibilities for burn operations with respect to safety:

3.2.1 **Burn Coordinator** provides the coordination link between all burn operations and the FOSC and the Unified Command. This person may be the Operations Chief for smaller spills where ISB is not occurring concurrently with other response operations. In larger spills, the Operations Chief may designate the burn coordinator. Also, the burn coordinator and the safety officer positions could be fulfilled by one person, depending upon his/her training and expertise.

3.2.2 **Safety Officer.** [This person may be the Safety Officer for the overall spill management or the Safety Officer's designee for ISB operations. For purposes of this document this position will be referred to as the Burn Safety Officer.] The responsibilities of the Burn Safety Officer for ISB operations include (but are not limited to):

- Ensuring worker health and safety during burn operations;
- Conducting pre-burn safety briefing on operational procedures and goals;
- Identifying potential emergencies;
- Explaining emergency communication protocols and emergency burn-termination criteria;
- Coordinating implementation of this plan;
- Assigning and monitoring activities of Deputy Safety Officers onboard each vessel;
- Maintaining this plan and providing daily updates (as needed);
- Acting as liaison with Site Safety Officers from other organizations participating in the response effort; and
- Reporting to the FOSC via the Burn Coordinator.

3.2.3 **Deputy Safety Officers.** The Burn Safety Officer designates a deputy onboard each vessel to monitor and track the condition of the fire relative to that vessel. Since the Burn Safety Officer will be onboard the ISB Command Vessel (' 3.4.1 below), an additional deputy safety officer is not required. Additionally, a deputy safety officer does not have to be an extra person on the vessel, necessarily. Other responsibilities include:

- Informing onboard personnel about safety measures specific to the particular vessels;
- Ensuring that vessel personnel understand emergency communications and procedures;
- Monitoring all safety aspects of the ISB response as it pertains to the particular vessel; and
- Reporting to Burn Safety Officer.

3.2.4 **Boom Commander.** Operations should ensure that one person controls boom logistics on the lead boom-towing vessel (see 3.3.3 below). For all boom-handling activities this person must work closely with the Burn Safety Officer to ensure efficient communication between the boom-towing vessels and other burn operations' vessels.

3.2.5 **Communications Unit Leader.** The communications unit leader, or designee, is onboard the command vessel. Responsibilities include:

- Ensuring effectiveness of overall communication of burn operations;
- Verifying communication links to each vessel and aircraft prior to ignition; and
- Reporting to the Burn Safety Officer.

3.2.6 **Air Operations.** Pilots of helicopters or fixed-wing aircraft used for aerial surveillance support for the burn and/or igniter deployment will brief the Burn Safety Officer on intended operations.

3.3 **Vessel Requirements**: The following vessels are required for safe burn operations (refer to the applicable burn operations plan for proper operational techniques.):

- ISB Command Vessel (1) to provide central command operations at the burn scene;
- Boom-Towing Vessels (2) to tow and control fire resistant boom;
- Fire-Control/Safety Vessel (1) to monitor burn and provide safety support;
- (Optional, as available) Helicopter or fixed-wing aircraft for aerial surveillance and/or possible igniter deployment.

If the burn operation consists of only one pair of boom-towing vessels, the command vessel and fire control/safety vessel could be combined.

[Please note that vessel requirements may differ from region to region depending on availability of vessels, location and remoteness of the spill, or the presence of ongoing extensive spill response operations.]

3.4 Responsibilities of Vessels

3.4.1 **ISB Command Vessel.** The Burn Safety Officer will be on the command vessel. The Burn Safety Officer reports to the FOSC, via the burn coordinator.. The command vessel controls all aspects of the burn, including the following:

- Ensuring overall safety, including adequacy of designated ISB location; absence of other sources of secondary ignition nearby; and safety of projected path of the sweep (while burning) for operators as well as the public;

- Communicating with all personnel involved in the burn to ensure awareness of events taking place before, during, and after the burn;
- Delivering or delegating final command for ignition of the burn.
- Maintaining communication with the FOSC;

3.4.2 **Safety Boat.** The safety boat's responsiblities include:

- Cross-checking to verify that all safety requirements of the burn are addressed;
- Monitoring and maintaining pre-designated "fire-free" zones;
- Reporting all hazards to command vessel;
- Preparing firefighting equipment (optional) onboard for accessibility and use;
- Assisting command vessel with burn observations and effectivness monitoring;
- Sampling[2] and recording to determine oil volume calculations prior to burn;

3.4.3 **Boom-Towing Vessels** are responsible for the following:

- Maintaining consistent tow speeds, boom configurations, and oil collection rates; and
- Performing emergency termination procedures.

Note: Boom-towing vessels do not necessiarily need fire-protective equipment. It is up to the individual organization's discretion. For example, the U.S. Navy Supervisor of Salvage (SUPSALV) carries fire-protective clothing for each person onboard and small fire pumps for each vessel, as added safety measures. Also, protective equipment is advised when using an igniter. People with protective equipment, however, may tend to assume adequate protection, and thus, move too close-in to the fire. If people are close enough to the flames to need fire-protective equipment, the vessel is also in danger.

[2] Samples include a 1-liter sample of collected oil (prior to burn) which will help determine length of the burn.

4 BURN AREA CONTROL

4.1 **Burn Plan**: In order to maintain organization within the response effort, a site-specific burn plan, or in-situ burn application[3], will be drawn up prior to ignition of the burn. To burn safely, the plan must include the following important considerations:

- Burn Feasibility: verification that window of opportunity exists for loft of smoke plume;
- Operational checklists: a chronological checklist of all operations critical for completion before, during, and after ignition;[2]
- Action plan: To supplement the operational checklists, a plan that details vessel deployment, method of ignition, weather forecasts, and water conditions for the specific geographic area; and
- Burn termination criteria: Should worker or public heath be threatened.

4.2 **Site Control**: Anyone entering or departing a burn area, or associated control zones, reports to the Burn Safety Officer. All persons entering the burn area must subscribe to this portion of the approved Site Safety and Health Plan by signature. All personnel will have adequate training on in-situ burn operations, and on hazardous waste operations safety and health (see Section 12 for training requirements).

4.3 **Traffic Control**: Movement of non-response vessels and aircraft in the vicinity of the burn may be affected by ISB response vessel activity and smoke production. Prior to and during burn operations, the response activity must be coordinated with the local airports, the FAA for Notice to Aviators, and the USCG for Notice to Mariners. Exclusion zones and traffic control corridors must be identified prior to ignition.

4.4 **Vessel Location**: An important consideration in maintaining the safety of response personnel is the location and placement of response vessels in relation to the burning slick. Location and movement of all vessels throughout the response effort will be planned prior to ignition of the burn. All vessels will remain out of the downwind quadrant. Ancillary vessels and aircraft non-essential to the burn must remain in pre-designated safe zones, traveling upwind and up current from the burning slick. To avoid exposure to excessive heat and to emissions, all vessels and personnel will remain at least five fire diameters away and upwind from the burn.

During the burn, towing vessels should be positioned so that there is an absolute minimal chance of being surrounded by, or coming into contact with, concentrations of oil that could pose a threat due to deliberate or accidental ignition.

4.5 Igniters

Ignition Safety: Ignition of the oil slick should receive careful consideration. Aircraft operations to ignite oil with gel or other aerial ignition methods must be well-coordinated. Weather and water conditions should be kept in mind, and proper safety distances adhered to at all times. Given the range of igniter types and ignition methods, manufacturer specifications for proper deployment will be followed.

4.5.1 Helitorch or Other Air-Deployable Igniter Systems:

IMPORTANT NOTE: The helicopter or fixed-winged aircraft deploying a Helitorch ignition or

[3] In-situ burn applications and operational checklists are region-specific.

other air-deployable igniter will maintain flight paths perpendicular to the boats and boom to eliminate flying over any vessels.

Type of Igniter:____
Additives:____
Manufacturer:____
Point of Contact:____
Attach an MSDS for additives and igniter contents.

4.5.2 **Hand-held Igniter Systems**: The person deploying the hand-held igniter will be trained in the use of the igniter. Follow safety recommendations of manufacturer.

Type of Igniter:____
Additives:____
Manufacturer:____
Point of Contact:____
Attach an MSDS for additives and igniter contents.

4.6 **Premature and Secondary Ignition Sources**: As with conventional oil containment measures, premature or accidental ignition of the slick must be avoided at all costs. Proper consideration must be given to the proximity of potential ignition sources to any combustible slicks up until the time of deliberate ignition. Also, before deliberate ignition, the wind and direction of tow will be considered to ensure that no one is within or near any potential large concentrations of vapors which might flash upon ignition. If atmospheric conditions are very still, considerable concentrations of ignitable vapors may collect in the atmosphere above the slick; ignition should commence from an appropriately safe distance. Monitoring should be considered to rule out unintentional ignition.

4.7 **"Go/No Go" Policy:** The organization must ensure delegation of authority of veto power, prior to ignition. Each deputy safety officer can veto the commencement or continuation of the burn based upon safety concerns within each area of responsibility. Each commander must ensure that all personnel are in the correct and safe place and that all equipment is in proper working order before ignition of the burn. **If an emergency situation arises after ignition of the burn, any deputy safety officer can terminate the burn by following emergency communication procedures (see Section 8.3.1.2).**

4.8 **Termination of Burn**: In most circumstances, the FOSC should plan to allow an oil slick to burn to completion once it has ignited. However, premature termination of a burn may be necessary if worker and public health is threatened due to a wind or weather shift, or a secondary ignition of another slick is a possibility. The fire may be extinguished prematurely by releasing the tow line from one of the towing vessels while the other moves ahead at several knots. This allows the oil to spread out quickly to a thinness that cannot support combustion. A second alternative is to move both towing vessels ahead at several knots, forcing the oil beneath the boom and removing it from the combustion zone. Refer to the applicable burn operations plan for more detail on terminating a burn.

4.9 Pre-Ignition Checks

Note: All radio frequencies and radio protocols should have been finalized prior to transit to the spill site.

1. Communications Officer performs a radio check and ensures that each vessel involved is aware of how much time is left before the ignition to burn. Also, the communications officer verifies that each vessel is aware of the designated burn trajectory.
2. Command vessel communicates with FOSC to obtain final approval to burn.
3. Command vessel communicates with helicopter and obtains verification of a clear burn path ahead

(assuming helicopter is available).
4. Burn safety officer ensures that boats and boom are pointed upwind (into the wind).
5. Burn safety officer reiterates the locations ofoil-free safe areas where vessels can retreat and regroup, should an emergency arise.

Contained oil should be ignited only after all pre-burn checks and requirements, as outlined in the FOSC approval applications and operational checklists, are met and confirmed via radio link with all vessel commanders and key participants.

(Refer to Annex C or the burn operations plan for detailed burn operations.)

5 HAZARD EVALUATION

5.1 **Airborne Particulates:** Considered by most experts to be the main airborne health hazard associated with in-situ burn emissions, particulates are small pieces of solid carbon or liquid hydrocarbon suspended in the air. Particulate matter is a by-product of incomplete combustion.

Hazard Description: Particulates less than 10 microns (millionths of a meter) in diameter can reach the deep portion of the lungs (the critical gas exchange area) and become a burden on the respiratory system. Thus the air quality standards are expressed as a fraction of particulates smaller than 10 microns in diameter (annotated as PM-10). The median size of particulates in the smoke from oil fires is 0.5 microns, posing a definite hazard to respiration. Studies show that the ground level concentrations of PM-10 nearby in-situ burn events usually remain below safety levels (except for the area directly in the smoke plume). For most people, exposure to inert particulates becomes a problem only at high concentrations. However, sensitive individuals may develop problems at levels much lower than that.

Permissible Exposure Limits (PEL) for PM-10: For **response personnel**, the following exposure limits apply:

OSHA PEL:	15 milligrams per cubic meter (mg/m^3) total particulate 8 hour mean
	5 mg/m^3 respirable particulates (PM-10) 8 hour mean

Symptoms of Overexposure: Excessive PM-10 will burden the respiratory tract and cause breathing difficulties.

Basic Precautions: Using respirators and eye protection suitable for protection from particulate matter will reduce exposure. The best precaution, however, is to avoid overexposure altogether. Keep vessels and personnel out of the smoke plume.

For hazards associated with other burn emissions constituents, refer to Annex D.

5.2 **Environmental Monitoring for Chemical Hazards**:

To ensure the health and safety of responders, the site safety plan must restrict all responders and response vessels from entering the smoke plume or from approaching the fire perimeter. Data analyzed from the Newfoundland Offshore Burn Experiment (NOBE) demonstrated that PM-10 levels were low upwind and outside of the smokeplume. Until further experience is gained, however, it is strongly recommended that PM-10 levels be monitored for worker's health and safety.[4]

[4] Guidance on monitoring is forthcoming from the NRT Science & Technology Committee. This document will be updated after such guidance is released.

Even though data on other ISB gaseous emissions suggest that concentrations do not seem to pose a risk if responders and vessels remain safe distances and upwind from the burn, concentrations of carbon dioxide are high at ground levels close to the burn. If for some reason, a responder must move close-in to the burn, proper personal protection equipment and monitoring must be administered. Additionally, a multiple burn scenario has not been tested. Should multiple burns be proposed, sampling for other hazards such as carbon monoxide, carbon dioxide, and polynuclear aromatic hydrocarbons, in addition to PM-10, is highly advised.

The following monitoring may be conducted; if used, monitoring equipment will be calibrated and maintained in accordance with the manufacturer's instructions (electronic equipment will be calibrated before each day's use):

INSTRUMENT	FREQUENCY
__ Combustible gas	___continuous, ___hourly, ___ daily, Other:
__ WBGT/heat stress	___continuous, ___hourly, ___ daily, Other:
__ Noise	___continuous, ___hourly, ___ daily, Other:
__ other chemical specific monitors (colorimetric/electronic):	
__ Particulate Monitors	___continuous, ___hourly, ___ daily, Other:
__ other	___continuous, ___hourly, ___ daily, Other:
__ other	___continuous, ___hourly, ___ daily, Other:

Zones of potentially hazardous substances may be encountered based upon wind and weather patterns. Projected extent and direction of plume of oil vapors prior to burn and smoke plume during the burn (along with any other applicable hazards found during the site survey) will be marked on the attached site maps.

5.3 Burn Hazards

Although safe practices should eliminate the possibility of a responder getting burned during an ISB, contingencies for such a scenario must be identified. Depending on the severity of the burn, damage inflicted will vary from superficial reddening of the skin to extensive surface blistering and death of underlying tissues. However serious, the correct first aid treatment is to cover the burnt surface with loosely applied, dry, sterile dressings. To reduce the dangers of infection, handling the burnt area must be reduced to a minimum and any temptation to clean its surface resisted. All burns of more than a trivial nature should be referred to the hospital.

5.4 Other Hazards:

Heat Proximity: Exposure of personnel to uncomfortable or dangerous levels of heat can be minimized or eliminated with proper considerations for vessel placement during a burn. Vessels should come no closer than five fire diameters for any extended length of time.

Heat Stress: In an in-situ burn event, the combination of hot weather and flame radiation can pose potentially dangerous situations for response personnel. Certain safety problems are common to hot environments. Heat tends to promote accidents due to slippery palms, dizziness, lower mental alertness, or fogging of safety glasses. If the victim is conscious and able to drink fluids, provide caffeine-free, cold liquids, preferably water.

Heat stroke is a serious condition which occurs when the body’s temperature regulatory system fails and sweating becomes inadequate. A heat stroke victim’s skin is hot, usually dry, red, or spotted. Body temperature is usually 105 degrees or higher, and the victim may be mentally confused, delirious, or unconscious. Unless the victim receives quick and appropriate treatment, brain damage and/or death can occur. Any person with signs or symptoms of heat stroke requires immediate hospitalization; however, first aid should be administered immediately with the intent to lower the body temperature. Move the victim to a cool area, thoroughly soak the clothing with cold water, and vigorously fan the victim.

Heat exhaustion is caused by the loss of large amounts of body fluid and salt through sweating. A victim suffering heat exhaustion usually still sweats, but experiences weakness or fatigue, giddiness, nausea, or headaches. Severe cases may exhibit vomiting or unconsciousness. The skin is clammy and moist, the complexion is pale or flushed, and the body temperature is normal. Treatment requires rest in a cool place and intake of liquids (caffeine-free).

Other hazards not ISB-specific: For other hazards refer to the general oil spill site safety plan for the incident.

6 PERSONAL PROTECTIVE EQUIPMENT (PPE) Refer to Annex A.

7 DECONTAMINATION PROCEDURES

Contaminated personnel, and personnel entering contaminated areas, will be decontaminated in accordance with the current work plan or attached decontamination layout.

8 EMERGENCY PROCEDURES

8.1 Emergency Medical Procedures

Refer to applicable section of the general site safety plan for the incident. IF an ISB-specific injury occurs:

- Contact the appropriate hospital or first aid station identified in ' 1, as appropriate.
- Dispatch medical aid from shoreside, as required.
- The Burn Coordinator will enlist assistance of crew from any vessel capable of rendering additional assistance.
- Medical evacuation by helicopter to the pre-identified hospital will be decided by the Burn Coordinator in conjunction with the Burn Safety Officer.

8.2 Emergency Fire Procedures:

- DO NOT attempt to fight fires other than small fires. A small fire is generally considered to be a fire in the early stages of development, which can readily be extinguished with personnel and equipment in the immediate area in a few minutes time.
- DO NOT take extraordinary measures to fight fires.
- You MUST sound the appropriate fire signal (three blasts with an air or foghorn) if fire cannot be put out quickly.
- Alert nearby personnel to call for assistance.
- Notify supervisor.
- The Burn Safety Officer will ensure that the fire is extinguished before restarting work.

8.3 Emergency Termination of Burn: Refer to Section 4.8 for burn termination procedures.

8.3 Communications

8.3.1 **Radio Communcation:** Dedicated radio links with specific frequencies will be established for vessel-to-vessel, vessel-to command, vessel-to-air, and air-to-air communications. Repeater stations will be arranged for as appropriate for distant or blocked communication paths.

Assignment of Frequencies:

Primary Command Channel (for general command communications):
Freq:__________ Channel:_____________ (VHF__ UHF__ CB__ Other_____)

Boom-Towing Vessel Channel (dedicated for boom-towing vessels):
Freq:__________ Channel:_____________ (VHF__ UHF__ CB__ Other_____)

Safety Vessel Channel (dedicated for routine communication):
Freq:__________ Channel:_____________ (VHF__ UHF__ CB__ Other_____)

Aircraft Channel (dedicated for aircraft):
Freq:__________ Channel:_____________ (VHF__ UHF__ CB__ Other_____)

Emergency Channel (dedicated for emergency communications):
Freq:__________ Channel:_____________ (VHF__ UHF__ CB__ Other_____)

Other: ____
Freq:__________ Channel:_____________ (VHF__ UHF__ CB__ Other_____)

8.3.2 **Emergency Communications:** An emergency can be communicated or declared using any of the above frequencies. All working frequencies will be monitored throughout the ISB effort by the command vessel and safety vessel. Once an emergency situation has been declared and identified, all response vessels will monitor the dedicated emergency radio channel for emergency instructions. The command vessel will request any further changes in radio channel selection as appropriate.

As part of the "go/no-go" policy, each deputy safety officer may stop the response effort by declaring an emergency. In declaring an emergency, the party must identify its vessel or operating unit and must provide a description of the problem.

In the event of radio equipment failure on any vessel, instructions to switch to other frequencies will be given by the communications officer on the command vessel.

8.3.3 **Emergency Phone Numbers**

On-Scene Coordinator:
(_____) _______________________ (__voice __fax __cellular __pager __home)
(_____) _______________________ (__voice __fax __cellular __pager __home)

Site Safety and Health Officer:
(_____) _______________________ (__voice __fax __cellular __pager __home)
(_____) _______________________ (__voice __fax __cellular __pager __home)

Burn Safety Officer:
(_____) _______________________ (__voice __fax __cellular __pager __home)
(_____) _______________________ (__voice __fax __cellular __pager __home)

Hospital:
(_____) _______________________ (__voice __fax __cellular __pager __home)
(_____) _______________________ (__voice __fax __cellular __pager __home)

If a victim is in route, alert the hospital for incoming patient with burn-related injuries.

9 TRAINING AND SITE SAFETY MEETINGS

9.1 **Training**: Prior to any response effort, all personnel must be OSHA and HAZWOPER training certified, as per 29 CFR 1910.120. Thereafter, classroom and/or hands-on refresher training must be completed by all personnel annually, emphasizing the particular hazards of a burn event to response personnel, equipment, and the general public. Training must also include experience with equipment and general response techniques, such as vessel operation, fire resistant boom deployment and towing, oil and residue recovery, ignition techniques, etc., to ensure safe operations.

9.2 **Burn Safety Meetings**: Prior to the commencement of the ISB response effort, a safety orientation for all personnel should be conducted. Burn safety meetings will then be held aboard each vessel prior to the ignition of the burn. At a minimum, these meetings will describe the work to be accomplished, safety procedure changes, and site-specific safety considerations.

Burn Safety Officer: ____

9.3 **Sign Up Sheet**

Team Member (Print Name)	Contact Number (Phone, Pager)	Signature	Date

Annex A: Personal Protective Equipment

A.1 **General Policy**: Employers are responsible for supplying personal protective equipment (PPE), as required by OSHA [29 CFR 1910.120 (g)]. Level of PPE should be evaluated based upon the threats identified in the site characterization and hazard evaluation. If an employer is providing equipment, including respirators [29 CFR 1910.134], OSHA regulations for training, selection, maintenance, and medical examination and monitoring must be followed.

According to safe in-situ burn practices, workers should be kept out of the smoke plume and at a safe distance from the fire, thus higher level PPE requirements may be unnecessary. People with fire protective equipment may feel overconfident in their protection and move too closely to the fire. If personnel are close enough to the flames to need this type of equipment, the vessel will also be in danger.

The recommended PPE ensemble is Level D for the entire burn response operation. During pre-ignition and the burn phase, personnel should have access to respirators and goggles. As a precautionary measure, flame and fire-resistant coveralls may be necessary for personnel on the safety vessel. (Refer below to specific ensemble configurations.)

Other issues to keep in mind include:

- Vessel of opportunity systems (VOSS) personnel must be properly fitted and trained prior to commencing operation.
- People handling burn residue need protective clothing.
- People handling igniters should use flame-resistant coveralls.

A.1.1 **Coverall Specification**: Coveralls will be of flame and fire resistant type, and lightweight to prevent overheating. Coveralls will be worn at all times by response personnel potentially at risk to exposure. During pre-burn, burn, and post-burn operations, fire-resistant coveralls should not be worn when directly handling spilled oil, because any oil that gets on the suit becomes potentially flammable.

A.1.2 **Respirator Specification**: Per 29 CFR 1910.134, a respirator will be provided for all personnel involved in the response effort. Those personnel required to wear a respirator must remove facial hair to enable a proper seal of the respirator against the face. During fit testing of respirators, responders will be given the option to select the most comfortable respirator.

A-2 PPE Ensembles

Level D Ensemble:

- Oil-resistant coveralls
  OPTION: Street clothing may be worn by supervisory personnel, technicians, specialist, etc., that will not be exposed to oil or the immediate flame proximity.
- Rubber steel toe/shank safety boots with textured bottoms
  OPTION: deck shoes with textured soles (for boat operations)
- Rubber/latex or leather work gloves
- Rubber rain pants, jacket, and hood (as needed)
- Rubber apron (as needed)
- Personal Flotation Device (PFD)
- Quart bottle to carry fluids (during heat stress alert)

- Hearing protection (ear plugs)
- Insect repellent (if necessary)
- Hard hat (not required on vessel decks unless overhead equipment is operating)
- Safety goggles
- Sunscreen

Level C Ensemble:

- Fire-resistant coveralls
- NFPA rated fire-resistant gloves
- Half or full mask cartridge respirator
- Fire-resistant hood
- Face shield, as required
- Dust, fume, mist cartridge
- Organic vapor cartridge (on-hand for oil vapors prior to burn)
- Goggles

Annex B: Contact List

Function and Name	Phone Number	Radio Contact
Federal On-Scene Coordinator:		
Site Safety and Health Officer:		
Burn Safety Officer:		
Command Vessel:		
Boom-Tow Vessel #1:		
Boom-Tow Vessel #2:		
Safety Vessel:		
Communications Unit Leader:		
Air Operations Leader:		
Scientific Support Coordinator:		
Other:		

Annex C: Burn Operations

C.1 **Boom Deployment**: Boom deployment will be consistent with the boom instruction manual. Deployment of the boom in an ISB response situation will be made easier and safer with planning and training of personnel well in advance of any response effort. Preparations for the following considerations should be completed in advance:

- Ensure that the boom is properly stored in the tray or storage container as specified so deployment is feasible without snagging or twisting. A single twist of the boom can render it nearly useless for oil containment at or near the twist. Attempting to untwist the boom by hand after deployment presents a hazard to personnel.
- During deployment, anticipate drag forces induced by vessel movement and natural currents. Avoid standing on or holding down boom during adjustments. Use proper tie-downs and anchor points to eliminate tension in the portion of the boom on which work is being done.
- Ensure that all tie-downs, tow lines, tow posts, etc., are strong enough to withstand the average and peak drag forces that may be experienced by the fire resistant boom in tow.
- Provide adequate communications between the boom-towing vessels and the personnel tending the boom out of its container or tray. Dedicated radio links and hand signals should be pre-designated in case of an emergency.

C.2 **Boom Towing**: Boom towing will be consistent with the boom instruction manual. The following are safety considerations during towing operations:

- To avoid overexposure to the intense heat of the flames, all vessels must remain at least 5 fire diameters from the flame perimeter. Downwind of the burn, the minimum approach distance will be necessarily greater to avoid emission exposure to personnel. For operations using 660 feet or less of boom, use tow lines approximately equal to the length of the boom. For boom lengths greater than 660 feet, tow lines may be less than the length of the boom. This allows for adequate distance between the towing vessels and the burning oil contained in the bottom third of the boom in a “U” configuration. Also, ensure that strength of tow lines can withstand the maximum anticipated tension forces induced by the drag force of the boom.
- Ensure that qualified aerial support is prepared with established communication lines to inform all responders of the location of boom-towing vessels relative to the target oil slick; other oil slicks in the same general area; other vessels in the area; and the anticipated region of influence from combustion products.
- Prior to ignition, ensure that all personnel on-site are positioned upwind or crosswind from the target slick.
- If response operations commence at or near the spill source, personnel and equipment will be positioned at a safe distance from any potential explosion or premature ignition of oil at or within the source.
- **Contained oil should be ignited only after all pre-burn checks and requirements, as outlined in the FOSC approval applications and operational checklists, are met and confirmed via radio link with all vessel commanders and key participants.**

C.3 **Boom and Boat Handling**: Refer to the instruction manual for boom and boat handling instructions. The designated boom commander ensures effective communication between the boom-towing vessels and other vessels. Once the oil is ignited, the boom commander remains in contact with the burn watch personnel described in Section 3.2. Proper attention to the status of the burn, the speed and positions of the towing vessels, and the proximity of the burn to other vessels, slicks, etc., must be maintained for quick response to dangerous situations. The boom-towing vessels will have a predetermined plan of communication and action for defined situations, such as: modification of the rate of burn (by modifying the size); requests of and offers for assistance to the sister towing vessel; and termination of the burn.

C.4 **Ignition Safety**: Ignition of the oil slick should receive careful consideration. Aircraft operations to ignite oil with gel or other aerial ignition methods must be well-coordinated. Weather and water conditions should be kept in mind, and proper safety distances adhered to at all times. Given the range of igniter types and ignition methods, manufacturer specifications for proper deployment will be followed.

C.5 **Fire Control**: Depending upon response operation circumstances, the ISB command vessel may wish to manipulate the combustion rate of the oil slick. The rate of combustion is directly controlled by the forward velocity of fire resistant boom-towing vessels. A slower velocity will increase the burn rate by increasing the spread of the oil, thus increasing the fire diameter. On the other hand, a faster velocity will decrease the overall rate of combustion. Care must be taken when manipulating the burn rate. Too thin of a slick will cease to burn, while too fast of a tow will cause oil splash-over.

C.6 **Burn Effectiveness Monitoring**: The dedicated safety vessel assists the command vessel with monitoring the burn's effectiveness. The safety vessel crew monitors the status of the burn in relation to the proximity of the burn to towing vessels and other response vessels. It also monitors and maintains pre-designated "fire-free" zones as needed between response vessels or between the burn and specified sensitive areas. Also, this vessel can provide backup support for deployment and containment operations, and provide extra personnel and equipment, where needed.

C.7 **Aerial Surveillance**: Aerial surveillance should continue, as available, throughout the burn to enhance status updating capabilities. Aerial surveillance should also provide early warning for wind and weather shifts which may impact the direction of the smoke plume.

C.8 **Termination of Burn**: In most circumstances, the FOSC should plan to allow an oil slick to burn to completion once it has ignited. However, premature termination of a burn may be necessary if the wind or weather shifts unexpectedly, or if secondary ignition of another slick is a possibility. The fire may be extinguished prematurely by releasing the tow line from one of the towing vessels while the other moves ahead at several knots. This allows the oil to spread out quickly to a thinness that cannot support combustion. A second alternative is to move both towing vessels ahead at several knots, forcing the oil beneath the boom and removing it from the combustion zone.

C.9 **Residue Collection**: The safety boat is in charge of collection of left-over debris or residue.

C.10 **Routine Communications:** The command vessel will provide general command functions for burn operations, and it will serve as the primary communications post. All radio frequencies will be continuously monitored by command personnel aboard the command vessel, and safety command personnel aboard the safety vessel.

Instructions regarding general response procedures will be communcated as necessary by the command vessel. Direct communication between the boom-towing vessels is necessary to ensure coordination of boom-handling procedures; this communication will be continuously monitored by the command vessel. Coordination of aircraft activity will be done through the command vessel.

Annex D: ISB Emissions

In addition to particulate matter less than ten microns in diameter (PM-10), other substances are emitted durning an ISB event. For example, small amounts of toxic gases, including sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO), are produced. Carbon dioxide is produced in levels that need consideration. Also, small amounts of polynuclear aromatic hydrocarbons (PAHs) present in the unburned oil are emitted from the fire as a product of incomplete combustion.

The above substances were sampled and analyzed extensively in the multi-national, multi-agency 1993 Newfoundland Offshore Burn Experiment, commonly referred to as "NOBE." From experience gained, data suggest that emitted gases pose minimal threats to worker health and safety, if vessels and personnel remain safe distances from the fire, and upwind from the smoke plume. However, questions still remain and caution must be taken as initial burns are tested in an operational response setting until further data are gathered to repeat and validate NOBE's findings. Secondly, different ISB scenarios such as multiple burns have not been studied. Therefore, should a responder need to move close-in to the fire PPE and monitoring should be administered.

The following table summarizes the health hazards associated with an ISB event.

Table 1: Hazard Evaluation

Type of Gas	***Hazard Description***	***Exposure Limits***	***Symptoms of Overexposure***
Particulate Matter < 10 microns (PM-10): Particulates less than 10 microns (millionths of a meter) in diameter can reach the deep portion of the lungs (the critical gas exchange area) and become a burden on the respiratory system. Thus the air quality standards are expressed as a fraction of particulates smaller than 10 microns in diameter (annotated as PM-10).	The median size of particulates in the smoke from oil fires is 0.5 microns, posing a definite hazard to respiration. Studies show that the ground level concentrations of PM-10 nearby in-situ burn events usually remain below safety levels (except for the area directly in the smoke plume). For most people, exposure to inert particulates becomes a problem only at high concentrations. However, sensitive individuals may develop problems at levels much lower than that.	OSHA PEL: 15 milligrams per cubic meter (mg/m^3) total particulate 8 hour mean 5 mg/m^3 respirable particulates (PM-10) 8 hour mean	Symptoms of Overexposure: Excessive PM-10 will burden the respiratory tract and cause breathing difficulties.
Polynuclear Aromatic Hydrocarbons (PAH): a group of hydrocarbons found in both unburned oil and the smoke plume. PAHs have very low vapor pressures, and most are not very flammable. In ISB, PAHs adsorb to particulates. Studies show that concentrations in the smoke remain below 0.01 ppm, below exposure limits.	Some PAHs are suspected carcinogens over a long-term exposure; the target organs being the skin and lungs. The hazard is minimal in in-situ burn events. Because of the high temperatures, most PAHs are burned in the combustion process, and the concentration is usually higher in the oil than in the smoke.	OSHA PEL: 0.2 ppm for 8 hours (for volatile PAH)	None.

Carbon Dioxide (CO_2): Colorless, odorless gas produced by burning fossil fuels.	High levels of CO_2 were detected at ground levels near the fire. Although detection hits were high (500-750 ppm), the levels were well below the exposure limit. Until further data are obtained, consideration to these findings is prudent.	OSHA PEL: 5000 ppm for 8 hour mean	Headache, dizziness, restlessness; parasthesia; dysphea; sweating; malaise; increased heart rate, elevated blood pressure; coma; asphyxia; convulsions.
Sulfur dioxide (SO_2) : colorless nonflammable poisonous gas with a pungent odor. The concentration emitted in a burn is directly related to the sulfur content of the oil.	Toxic gas and a corrosive irritant to eyes, skin, and mucous membranes by forming sulfuric acid on these moist surfaces. The gas may reach the deep portion of the lung, but not as much as other, less soluble gases. The danger from in-situ burning is minimal; studies indicate that sulfur dioxide emissions remain significantly below the exposure limits.	- NAAQS: 0.14 ppm for 24 hours - OSHA PEL: 2 ppm for 8 hours	Irritation of eyes, skin, mucous membranes, and respiratory system.
Nitrogen dioxide (NO_2): toxic gaseous by-product of oil combustion. It is normally a red-brown gas with an irritating odor.	Extremely toxic to humans by inhalation. It is less soluble than sulfur dioxide, so it can reach the deeper portions of the lungs (the critical gas exchange area). Small concentrations can cause pulmonary edema, which can be delayed. Nitrogen dioxide is also a strong irritant to eyes and respiratory tract. Studies of in-situ burn events have shown that concentrations of nitrogen dioxide in smoke emissions remain below 0.02 ppm; well below exposure limits.	- NAAQS: 0.053 ppm for 24 hours - OSHA PEL: 1 ppm for 8 hours	Irritation of eyes, skin, and mucous membranes.

***Carbon Monoxide (CO)*:** product of incomplete combustion of oils. It is a colorless, odorless gas that is toxic to humans.	The toxicity of carbon monoxide is acute: it has a high affinity to hemoglobin in the blood, displacing oxygen and ultimately causing oxygen deprivation in the body's cells. The hazard of carbon monoxide from burn emissions is minimal. Data so far suggest that concentrations in oil fire smoke remain below 5 ppm 150 meters downwind; well below exposure limits.	- NAAQS: 9 ppm - OSHA PEL: 35 ppm for 8 hours	Headache, nausea, dizziness, confusion; at high concentrations asphyxia and death may result.

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Residues from In-Situ Burning of Oil on Water

The small amounts of residue from in-situ burning (ISB) of oil on water, particularly if the residue sinks, can cause environmental concerns. Results of laboratory tests suggest the possibility that, for about 40 to 60% of crude oils worldwide, burn residues may sink. However, whether results from laboratory tests can be extrapolated to large-scale spills is not known. Burn residues have little to no acute aquatic toxicity. Their greatest impact would likely be to the benthos from smothering. For most ISB applications, impacts would be very localized because of the small volumes of residues generated and their dispersal by currents.

Background and Status of Knowledge

Residues of oils burned in laboratory tests in the 1970s and 1980s floated, probably because of the small scale of those tests and the thinness of the burned oil. The 1991 Haven spill, in which large amounts of heated and burned oil residue sank, stimulated research into whether residue density affects whether a residue will float or sink.

Results from recent larger-scale laboratory and meso-scale field tests suggest that the most important factors determining whether an ISB residue will float or sink are:

1. *Water density*
   Burn residues that are denser than the receiving water are likely to sink. The density of fresh water is 0.997 g/cm3 at 25°C, and the density of sea water is 1.025 g/cm3.
2. *Properties of the starting oil*
   Correlations between the densities of laboratory-generated burn residues and oil properties predict that burn residues will sink in sea water when the burned oils have (a) an initial density greater than about 0.865 g/cm3 (or API gravity less than about 32°) or (b) a weight percent distillation residue (at >1000°F) greater than 18.6%. When these correlations are applied to 137 crude oils, 38% are predicted to sink in seawater, 20% may sink, and 42% will float.
3. *Thickness of the oil slick*
   Residues from burns of thick crude oil slicks are more likely to sink than residues from burns of thin slicks of the same crude oils, because higher-molecular weight compounds concentrate in the residue as the burn progresses.
4. *Efficiency of the burn*
   Factors affecting burn efficiency include original slick thickness, degree of emulsification and weathering, area coverage of the flame, wind speed, and wave choppiness. For efficient burns, removal efficiencies are expected to exceed 90% of the collected and ignited oil. Rules of thumb for predicting residue thickness are [2]:
   - For unemulsified crude oil up to 10-20 mm thick, residue will be about 1 mm thick.
   - Thicker slicks result in thicker residues (up to 3-6 mm thick).

- Emulsified oils can produce much thicker residues.
- For light/medium refined products, the residue will be about 1 mm thick, regardless of slick thickness.

When burn residues sink, they do so only after cooling. Models of cooling rates predict that ambient water temperature will be reached in less than 5 minutes for 3 mm-thick residues, and in 20-30 minutes for 7 mm-thick residues [6].

Physical properties of burn residues depend on burn efficiency and oil type. Efficient burns of heavy crudes generate brittle, solid residues (like peanut brittle). Residues from efficient burns of other crudes are described as semi-solid (like cold roofing tar). Inefficient burns generate mixtures of unburned oil, burned residues, and soot that are sticky, taffy-like, or semi-liquid.

Chemical analyses of burn residues show relative enrichment in metals and the higher-molecular weight PAHs, which have high chronic toxicity but are thought to have low bioavailability in the residue matrix. Bioassays with water from laboratory- and field-generated (NOBE) burn residues of Alberta Sweet Mix Blend showed little or no acute toxicity to sand dollars (sperm cell fertilization, larvae, and cytogenetics), oyster larvae, and inland silversides [3]. Bioassays using NOBE burn residues showed no acute aquatic toxicity to fish (rainbow trout and three-spine stickleback) and sea urchin fertilization [1]. Bioassays using laboratory-generated Bass Strait crude burn residue showed no acute toxicity to amphipods and very low sublethal toxicity (burying behavior) to marine snails [4].

Localized smothering of benthic habitats and fouling of fish nets and pens may be the most significant concern when semi-solid or semi-liquid residues sink. At the Honan Jade spill, burn residue sank in 2 hours and adversely affected nearby crab pens5. All residues, whether they floated or sank, could be ingested by fish, birds, mammals, and other organisms, and may also be a source for fouling of gills, feathers, fur, or baleen. However, these impacts would be expected to be much less severe than those manifested through exposure to a large, uncontained oil spill.

Current Research

The Minerals Management Service is funding a project to develop standard laboratory tests for assessing suitability of an oil for burning. Environment Canada is analyzing residues from burns that they attend.

Consequences to Operations of Uncertainty of Research Information

Because of uncertainties in extrapolating laboratory results to actual spill conditions, responders cannot confidently predict the amount of residue that may be generated by burning of heavy crude oils and refined products or if/how much of the residue will float or sink.

Only a very short time window is available for surface recovery of residues that eventually sink, but this recovery option could be effective, since residues are readily recovered either manually or with sorbents. Limitations include logistics, worker safety, and slow-down in ISB operations. Residues may be re-burned as more oil is collected and burned. Once the residue sinks, recovery options are few, logistics-intensive, and ineffective.

Needed Research

Field trials and study of actual spills where ISB is conducted are needed to determine whether or not the small-scale test data and predictive models developed to date apply to large burns. These models then should be refined.

Chronic toxicity tests using burn residues, benthic organisms and habitats, and realistic exposure levels and pathways also are needed.

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Source: Office of Response Restoration, National Ocean Service, National Oceanic and Atmospheric Administration http://response.restoration.noaa.gov/index.php

ISB Comparisons

The Newfoundland Offshore Burn Experiment (NOBE), so far the largest-scale experimental in-situ burn, took place on August 12, 1993, offshore of Newfoundland, Canada, and was organized and coordinated by Environment Canada. During each of two test burns, crude oil was poured into a U-shaped fire-proof boom, and ignited. The first test burn lasted for an hour and a half, the second for about an hour, with an average burning rate of 200 barrels of oil per hour observed during both burns.

Table 1, below, compares the rate of emissions generated by the NOBE test burns to typical rates of emissions from slash burns of agricultural debris and other emission sources, such as woodstoves and power plants. Most of the information in this table was produced by Dr. Ron Ferek of the University of Washington in Seattle. Dr. Ferek assumed an oil burning rate during the NOBE burns of 200 barrels per hour.

In Table 1, the **Average Emission Factor** is the quantity in grams of a particular substance, such as CO2, emitted when 1 kilogram of oil was burned during NOBE. **Emission Rate** is the rate of emission of a particular substance measured during NOBE, in kilograms per hour. The **Comparable Emissions** column displays the magnitude or number of other emission sources that would produce about the same amount of a given substance as was generated by burning 200 barrels of oil during NOBE. For example, a 2-acre slash burn would generate about as much CO2 as burning 200 barrels of oil.

Table 1. Emission rates from the NOBE test burns and other known sources.

Substance	Average Emission Factor for NOBE (g/kg fuel burned)	Emission Rate (kg/hr)	Comparable Emissions from Other Known Sources
CO2	2,800	75,600	approx. 2-acre slash burn
CO	17.5	470	approx. 0.1-acre slash burn or ~1,400 wood stoves
SO2	~15	405	7400 kg/hr. (avg. coal-fired power plant)
Total smoke particle	150	4,050	approx. 9-acre slash burn or ~58,000 wood stoves
Sub-3.5-micrometer smoke particle	113	3,050	approx. 9-acre slash burn

Sub-3.5-micrometer soot	55	1,480	approx. 38-acre slash burn
PAHs	0.04	1.1	approx. 7-acre slash burn or ~1,800 wood stoves

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You can learn more about NOBE by reading the following reference:

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You can learn more about Dr. Ferek's research from:

Ross, J. L., R. J. Ferek, and P. V. Hobbs. 1996. Particle and Gas Emission from an In Situ Burn of Crude Oil on the Ocean. Journal of the Air and Waste Management Association: 46 251-259.

From:
Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration

SMART

Special Monitoring of Applied Response Technologies (SMART) is a cooperatively designed monitoring program for in situ burning and dispersants. SMART relies on small, highly mobile teams that collect real-time data using portable, rugged, and easy-to-use instruments during dispersant and in situ burning operations. Data are channeled to the Unified Command (UC) (representatives of the spiller and the state and federal governments who are in charge of the spill response) to address critical questions:

- Are particulates concentration trends at sensitive locations exceeding the level of concern?
- Are dispersants effective in dispersing the oil?

Having monitoring data can assist the Unified Command with decision-making for dispersant and in situ burning operations.

The SMART program is a joint project of these agencies:

- U.S. Coast Guard
- NOAA
- U.S. Environmental Protection Agency
- Centers for Disease Control and Prevention
- Minerals Management Service

The SMART Way

Dispersants
To monitor the efficacy of dispersant application, SMART recommends three options, or tiers.

Tier I: A trained observer, flying over the oil slick and using photographic job aids or advanced remote sensing instruments, assesses dispersant efficacy and reports back to the Unified Command.

Tier II: Tier II provides real-time data from the treated slick. A sampling team on a boat uses a monitoring instrument to continuously monitor for dispersed oil 1 meter under the dispersant-treated slick. The team records and conveys the data to the Scientific Support Team, which forwards it, with recommendations, to the Unified Command. Water samples are also taken for later analysis at a laboratory.

Tier III: By expanding the monitoring efforts in several ways, Tier III provides information on where the dispersed oil goes and what happens to it.

1. Two instruments are used on the same vessel to monitor at two water depths.
2. Monitoring is conducted in the center of the treated slick at several water depths, from 1 to 10 meters.
3. A portable water laboratory provides data on water temperature, pH, conductivity, dissolved oxygen, and turbidity.

In Situ Burning

For in situ burning operations, SMART recommends deploying one or more monitoring teams downwind of the burn, at sensitive locations such as population centers. The teams begin sampling before the burn begins to collect background data. After the burn starts, the teams continue sampling for particulate concentration trends, recording them both manually at fixed intervals and automatically in the data logger, and reporting to the Monitoring Group Supervisor if the level of concern is exceeded. The Scientific Support Team forwards the data, with recommendations, to the Unified Command.

Field Experience

SMART has already been successfully tested in the field. SMART was used to monitor dispersant applications in the Gulf of Mexico, and in February 1999 it was used to monitor the in situ burning of the New Carissa, a freighter grounded offshore of Coos Bay, Oregon. Spills and exercises like these help us to enhance SMART.

SMART Materials

- SMART: A Guided Tour View a guided tour of information about SMART.
- Special Monitoring of Applied Response Technologies (SMART) The SMART protocol, last updated in August 2006.
- In Situ Burning More information about in situ burning and burn monitoring

From: Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration