Field Operations Guide for In-Situ Burning of Inland Oil Spills

API TECHNICAL REPORT 1251
FIRST EDITION, JULY 2015

AMERICAN PETROLEUM INSTITUTE

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Foreword

American Petroleum Institute (API) publications necessarily address problems of a general nature, with respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Contents

Purpose of this Field Operations Guide

This is a field operations guide. It is not an educational or decision-making tool. This Guide contains a set of operational checklists, tools, and references to assist in the conduct of inland in-situ burning (ISB) of spilled oil.

Priorities for Oil Spill Response

- People—safety of response personnel and the public.
- Environment—prevention of environmental, human health, and welfare effects.
- Assets—minimizing damage to structures and equipment.

Safety

Responder safety and health must never be compromised for tactical considerations. Likewise ISB should be conducted to minimize smoke/particulate safety and health impacts to responders, the public, occupied areas, roadways, etc.

Intended Audience

This Guide is intended for experienced response operations personnel having basic knowledge or expertise in ISB. Although widely applicable, this Guide reflects research and experience in North America.

How to Use this Field Guide

A decision to use ISB with appropriate local, state, and/or federal approvals should already have occurred before field operations commence. The decision to pursue burn should be made early in an incident, taking into account its feasibility and appropriateness and with guidance from Incident Command/Unified Command to make best use of windows of opportunity.

Operations managers should then use this Guide to develop timely plans, brief personnel, and manage operations. Environmental staff should ensure that operational plans conform to any permission requirements or permit conditions.

- The included checklists provide guidance to develop operational arrangements to support ISB at inland locations.
- Verification of continued favorable burning conditions must occur throughout preparations and just prior to ignition. General and habitat-specific listings of such conditions are included.
- The scale of an ISB and its duration will significantly affect the potential hazards, permissions required, operational staffing, management structure, and intensity of any air quality monitoring. This Guide is intended to be incident scale-neutral.
- When encountering unfamiliar terms or acronyms, please refer to the Glossary.
- Appendices provide additional detail on specific operational considerations.

Field Operations Guide for In-Situ Burning of Inland Oil Spills

Introduction

This Guide is intended to assist oil spill responders who are considering or executing controlled in-situ burning of an inland spill. In-situ burning (ISB) is the combustion of hydrocarbon vapors from spilled oil which are converted predominantly to carbon dioxide and water and released to the atmosphere. ***In situ*** means "in place" in Latin.

The basic objectives of an ISB operation are to:

1. Safely and efficiently remove as much oil as possible from a surface to reduce any environmental impact;

2. Lessen any potential physical damage to habitats from exposure to oil while removing oil from sensitive environments or areas of economic or social importance.

This Guide is intended primarily as a field guide for experienced personnel, as opposed to an educational or decision-making tool. It is assumed that users have basic knowledge or expertise in ISB, so the Guide primarily functions as a set of checklists, tools, and references to assist in conduct of ISB.

- The inland environments in this Guide include terrestrial or upland areas such as grasslands, savannas, forests, deserts, and open agricultural fields, as well as lakes, ponds, rivers, streams, associated wetlands, and other freshwater environments. Near shore marine and estuarine environments are included in this Guide. All environments are considered with and without show and ice.

- This Guide is intended for all sizes of an incident, since even small, localized incident responses should follow the same basic procedures as a large incident.

Specific In-Situ Burning Considerations

Tactical decisions as well as the nature and amount of resources needed to conduct a safe and effective burn depend upon the size of the expected burn(s); the volume and condition of the oil spilled; the type of release (i.e. batch vs. continuous spill); the proximity of intended burns to their source; and whether the spill source is already ignited, or could be ignited accidentally.

The safety of personnel will always be of paramount importance. Sometimes safety considerations will drive use of specific procedures for ignition and sustained combustion of highly volatile fluids.

Oil Types

It is assumed that the type of oil to be burned is crude oil, diesel, or other petroleum product, which can be burned safely. Lighter petroleum products such as gasoline are typically considered too volatile for a safe burn. The condition of the oil, its weathering state and ability to ignite and burn, is key.

Location Considerations

ISB should be conducted at locations sufficiently removed from an unignited spill source for fire control purposes, especially when oil is still being released. Many inland locations may be conducive to a safe and efficient ISB. In some situations, burning may be the only means of both quickly and safely removing large amounts of oil.

Requirements to Ignite and Sustain an ISB

ISB requires fuel, oxygen, and an ignition source. Fuel for a burn is provided by the vaporization of oil, which is increased by the heat from a fire. To sustain a burn, there needs to be adequate oil for continued vapor generation sufficient to yield steady-state (sustained) burning. The thicknesses required to ignite and sustain combustion depend upon the volatility of an oil, its emulsification (or water content), and wind and sea state conditions. Ignition of spilled oil is especially dependent upon these conditions because of the limited size and intensity of most ignition devices.

- Volatile fractions can quickly evaporate from spilled oil and render it too heavy for a sustained burn. An oil spill over approximately four or five days old may be impossible to ignite or a burn impossible to sustain without use of very hot and long burning ignition devices.

- Once ignited, spilled oil will tend to burn down to a thickness of about 1 mm on water. On soil, the oil soaks in to varying extents, and there is often combustible organic material (vegetation), which contributes fuel for a more complete burn.

- For a burn to be ignited and sustained on water, the spilled oil must be at least 1/10 in., or 2–3 mm, in thickness. For heavier and emulsified oils up to 10 mm in thickness may be necessary to generate burnable vapor concentrations.

Containment

Containment of some form is usually necessary to limit spreading of an oil slick and maintain necessary thickness for ignition and sustained burning. There can be sufficient sorption of oil on soils and vegetation that there may be little horizontal movement.

- On land, spilled oil can be contained by physical means (such as by dikes, snow berms, or ditches). Spilled oil will also collect in natural depressions or low-lying areas where it can be contained and ignited.

- Other types of physical containment (e.g. snow, ice, debris, shorelines) can provide barriers against spreading of oil to support ISB.

- On inland waters, spilled oil can be contained within a fire-resistant boom or naturally in ice, or it can be held by wind against a shore or dam.

- Ambient winds and chemical herders can also help drive oil slicks on water against natural or manmade barriers to thicken oil and support combustion.

ISB Decision-Making Components

ISB quickly and significantly reduces the amount of spilled oil on land or on water surfaces, thereby preventing longer environmental exposure times or spilled oil affecting additional, natural resources and/or habitats. ISB can also reduce ground level air emission concentrations, typically making the post-burn work environment safer for response crews.

The decision to pursue and conduct an on-water burn should take into account the feasibility and appropriateness of ISB. Checklists are provided in this Guide to help address issues involving:

- nature and distribution of spilled oil;
- size and condition of the spill source (a batch or continuous release);
- potential for accidental ignition of the source or other facilities nearby;
- environmental conditions which might preclude a successful ignition and sustained burning, etc.

Once it is determined that a safe and effective burn can be conducted, such information can be used by planners to secure appropriate approvals and resources to carry out the burn(s). Once approved, operations managers should share site-specific burn plans, mobilize resources, brief personnel, and coordinate all offshore, shoreline and air operations.

The focus of this Guide is on the operational plans and implementation of the ISB, not the decision-making process. The Guide should serve as a field reference and summary of key factors in executing safe and effective controlled burns in inland environments once the decision to burn has been made and approved.

ISB Field Operations Checklists

Including Confirming Planning Considerations

General Precautions and Preferred Conditions

- **Winds—**<12 mph (10.5 knots or 19 km/hr) for ignition for better fire control; sustained burning is possible with higher wind conditions.
- **Oil—**at least 2 to 3 mm thick to burn on water (thickness on soil may be less, as determined by a test burn).
- **Standing water—**at least 2 mm deep or well saturated soils with water to soil surface can protect plant roots from heat, particularly applicable for Marshes and Tundra.
- **Peat bogs—**if dry, may catch on fire, are very difficult to extinguish and burning may persist for a long time.
- **Deserts—**consider only burning in non-vegetated areas, between plant groupings and in dry streambeds.
- **Forests—**ISB is generally discouraged but may be acceptable in certain conditions.

Prerequisites

- ☐ On scene conditions continue to justify, and satisfy requirements for, ISB (Appendix A).
- ☐ Human populations are at a safe distance from anticipated fire and smoke (Appendix A).
- ☐ ISB can be conducted safely (Appendix B). A Site Safety Plan specific to a planned burn has been developed, approved, and communicated.
- ☐ Weather forecast indicates suitable conditions will persist over the estimated burn-time window (Appendix C).

- ☐ Oil on bare soil or on water is contained by natural barriers (plants, wind, and topography), or by booms; creating a minimum oil thickness of 2–3 mm for successful ignition.

- ☐ For on-water burns, current and sea state is low enough so that entrainment and loss of oil under containment is precluded.

- ☐ Oil is fresh enough and has enough volatile hydrocarbons to allow ignition and there is sufficient oil and vapors for sustained burning (Appendix E). A test ignition is suggested and may be required.

- ☐ Access (weight, width, turn radius) for fire control, rescue, and monitoring is adequate.

- ☐ Fuel load (vegetation and oil) has been evaluated (if possible by a wildland, prescribed burn specialist/qualified Burn Boss) for inland and upland areas including fields, prairies and savannas.

- ☐ Federal, state, and local approvals have been obtained; consultations have been made.

- ☐ All necessary permits have been obtained and are available onsite.

- ☐ The Responsible Party/Parties, property owner(s), and incident management have given written consent to conduct of a burn.

Logistical Considerations

Personnel

- ☐ Personnel have been identified and assigned for:
    - Command and Communications.
    - Safety.
    - Environmental Protection.
    - Ignition Operations.

- Fire Surveillance.
- Pollution Monitoring.
- Unburned Residue Recovery.
- Post-Burn Activities (including residue recovery, burn volume estimation, equipment decontamination, photographic and environmental documentation).

- [ ] Emergency Medical, Rescue, and Fire Suppression Teams have been established.
- [ ] ALL personnel are appropriately trained and/or experienced for their roles.
- [ ] Appropriate personal protective equipment (PPE) and safety gear is available, distributed and personnel are trained on its use.
- [ ] Hydration, toilets (and in cold conditions warming stations), and food supplies are available.
- [ ] Burn area maps and communications call lists have been prepared, verified, and distributed to ALL operations personnel.
- [ ] All operations personnel have been briefed on:
    - Safety (including health signs and symptoms of exposure and what to do about it).
    - Ignition and sustained burn plan.
    - Fire control and suppression.
    - Habitat, wildlife, and environmental protection.
    - Emergency response tactics.

Staging

- ☐ Staging areas are identified.
- ☐ If needed, field heliports, or helispots, are identified and marked for:
  - ○ Medical evacuation/Air ambulance procedures.
  - ○ Aerial ignition support base (if used).
- ☐ Radios and cell phone coverage in all parts of the operational area are verified.
- ☐ Radio channels are established for:
  - ○ Command and Control.
  - ○ Ignition Team.
  - ○ Fire Surveillance Team (where needed).
  - ○ Air Quality Monitoring Team.
  - ○ Other teams, as deemed necessary and appropriate.
- ☐ Ignition equipment, hand-held (drip torches, propane weed burners, etc.), and/or helicopter-deployed capability [helitorch or plastic sphere dispensers (PSDs)] are in place (Appendix E). In cold conditions, these must be able to provide high-temperature and sustained heat to ignite cold oils.

Location Considerations

Terrestrial Burning

- ☐ Fire suppression equipment and personnel to operate it, are sufficient and in place.

- ☐ Water supply for fire suppression of ISB meets these requirements:
  - ○ Suitable apparatus is available.
  - ○ Sources identified.
  - ○ Sufficient capacity verified.
  - ○ Delivery time and quantities adequate.
- ☐ Firebreaks have been constructed where needed (Appendix D). In ice and snow conditions berms may be constructed of ice and snow.

Open and Flowing Water

- ☐ Fire-resistant boom of sufficient length is available (Appendix D). A typical length is 500 ft per burn team towing unit.
- ☐ Conventional containment boom (for diverting or defecting oil to the burn containment operation) is available.
- ☐ Towing gear (non-metallic towlines, 200–500 ft at each end of towed boom) is available.
- ☐ Anchors, boom vanes, and shore mooring points are available in quantities needed for deflection booms and burn containment operations.
- ☐ Boat or shore access is available for:
  - ○ Boom deployment (towing capacity of boat engines is critical).
  - ○ Fire surveillance.
  - ○ Air quality monitoring.
  - ○ Rescue team.

   - Recovery of unburned residues.
   - Decontamination for boats and boom.

Ice Conditions

- ☐ For ISB on solid ice over water:
   - Thickness and integrity of ice is verified for all operations that require any personnel or equipment on ice.
   - Chain saws and ice augers are available in needed sizes.
   - Lifting equipment is available to remove ice blocks from trenches.
   - Storage/containment areas for any oiled ice are established.
   - Appropriate equipment if constructing snow berms on ice.
- ☐ For ISB on broken ice on water:
   - Booms to contain oil when ice coverage is less than 20%.
   - Chemical herder and an application system to increase the thickness of oil when it is not naturally contained at an ignitable thickness by the confining action of the ice.

☐ Refer to the companion API Technical Report 1252, *Field Operations Guide for In-Situ Burning of On-Water Oil Spills.*

Monitoring, Notifications, and Documentation

Monitoring

- ☐ Air monitoring equipment for particulates, lower explosive limit levels, volatiles, and poly aromatic hydrocarbons are functional, calibrated and deployed (Appendix G).

- ☐ Equipment for unburned residue recovery is identified and in place:
  - Large sheets of plywood or similar materials laid over marsh/tundra can distribute the weight of personnel and minimize trampling oil into substrate.
  - Sorbents.
  - Rakes, shovels, pitch forks, nets.
  - Heavy equipment (e.g. excavators, track hoes, bobcats, bulldozers, etc.).
  - Storage facilities (lined pits, containers, etc.).
- ☐ Equipment for recording pre- and post-burn status (cameras, water- and beach-sampling materials as appropriate). Documentation of fire size, location, and duration of burn for burn volume estimates. Recording of multiple burns, amount of burn residue produced and collected, etc.

Public Safety Notifications

- ☐ Local emergency management and law enforcement agencies have been notified, particularly with respect to potential visibility impacts to local roads and highways (aircraft, road and waterborne traffic, and spill response personnel).
- ☐ Roads, where visibility can be impacted by smoke, are closed and traffic detoured.
- ☐ FAA has been notified of possible smoke impacts to air traffic, as appropriate.
- ☐ Nearby residents have been notified and/or temporarily relocated if likely to be impacted by smoke.
- ☐ The local 911 public safety answering service has been briefed on the burn and any likely smoke plume concerns.

☐ Public relations contact has been identified and briefed.

ISB Plan Components of an Incident Action Plan

☐ An ICS for this ISB has been established (Appendix I).

☐ Incident Command conditions and requirements for ISB have been incorporated into plans, as necessary.

☐ Requirements of all local, state, and federal permits have been communicated, and incorporated into plans, as necessary.

☐ ***Site Safety Component*** (Appendix B) including:

- ○ ***Emergency Contingency Component*** addressing:
    - Monitoring (wind/weather conditions, visibility, temperature, etc.).
    - Fire control (type, amount, location, personnel).
    - Medical/Rescue (air ambulances will usually not transport contaminated patients).
    - Emergency communications.
    - Rapid notification and evacuation of response personnel.

☐ ***Ignition Plan Component*** requirements:

- ○ Personnel are identified.
- ○ Burn time estimated and ignition timing criteria are established.
- ○ Ignition equipment function is checked.
- ○ Ignition tactics identified (examples are below):
    - For marshes, deserts, tundra, and upland areas including fields, prairies, and savanna, tactics might include ignition upwind, downwind backfires, and

sequencing of ignition to give better control depending upon wind direction and safety considerations.

- For open water, tactics might include towed fire boom, wind herding, and prop wash herding.
- For flowing water, tactics might include deflection booming and towed fire boom (with or against current).

- Consider batch burning of slick segments for better control of fire propagation.
- Firebreaks are verified for desert, marsh, tundra, and upland areas including fields, prairies, and savanna.
- Test burn is conducted with the igniter of choice, particularly for emulsified (consider using an emulsion breaker) or weathered oil.

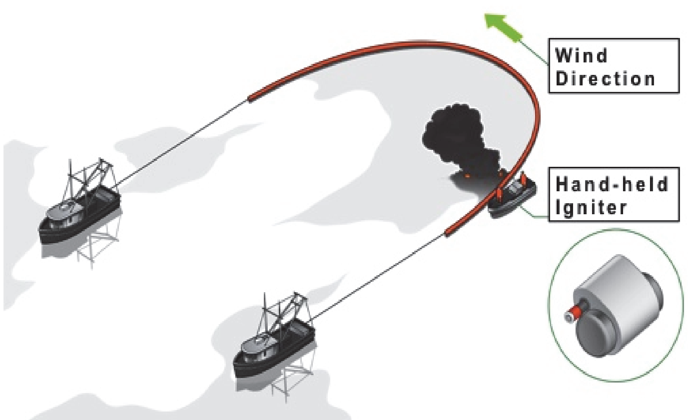
☐ ***Fire Surveillance*** requirements:

- Observation locations are identified.
- Personnel are assigned.
- Action criteria are established.

☐ ***Fire Suppression*** requirements:

- Apparatus/equipment is available (even on water: fire extinguishers/monitors are on boats and shore-side burn locations).
- Personnel are assigned.
- A sufficient water supply, or other materiel (e.g. foam), is accessible for suppression.
- When using towed booms on water, consider a rapid-release tow harness.
- Foam: supply and deployment plans exist.

- ☐ ***Oil Concentration Component*** for surface water:
  - ○ Increase oil thickness to burnable depth (minimum of 2–3 mm) and concentrate oil thickness to increase efficiency of burn.
  - ○ Use wind or prop wash to concentrate oil on fire boom or along non-vulnerable shoreline.
  - ○ Use diversion boom to deflect oil in current to burn area (boom with shorter skirts is used to reduce entrainment).
  - ○ Use two boats to capture oil in a fire boom catenary pocket.
  - ○ Use a two-boat task force moving with current to capture oil in fire boom catenary (boom to have relative velocity to stream flow of less than 0.7 knots) for burning.



Fire Boom Deployed Using Two Vessels with Hand-Held Ignition

Drawing courtesy of BP.

  - ○ In conjunction with above tactic, use two additional and more widely separated boats towing a diversion boom upstream in a V or funnel configuration, which collects oil over greater water area because the funnel feeds concentrated oil towards the burn.

- ☐ ***Oil Collection*** requirements for snow:

  - For oiled snow on any hard surface, if the snow can be gathered and the oil absorbed to snow concentrated, then it is possible to burn. Mechanical equipment can be used to move large volumes of oiled snow.

  - Best results have been with oiled snow collected into cone or volcano shapes so oil settles near the bottom at higher concentrations. For these conditions, an ignition aid could be needed.

  - Ignitability will depend on oil type, quantity, and winds. If snow: oil volume is ~25%–40% near the bottom center of a cone, then it is possible to ignite. Ignition may be possible at higher snow ratios.

Burning Oiled Snow

Photo courtesy of ACS.

- ☐ ***Oil Collection*** requirements for broken ice on water:
  - As ice conditions increase beyond 20% to 30%, controlled ISB operations without boom can often be done successfully where the ice limits the spreading of oil and the minimum oil thickness for ignition is maintained.
  - Use hand-held igniters or helitorch to ignite oil between ice leads.
- ☐ ***Oil Collection*** requirements for solid ice on water:
  - Assess ice strength for tolerance of equipment and responders.
  - Slots cut in ice to collect oil to be 1.5 to 2 times as wide as ice is thick, oil will migrate to slots.
  - If flowing water is under ice, angle slots 30 degrees to the current flow.
  - A hole in the ice surface or in an ice trench may release trapped oil, which can be burned.
- ☐ ***Aviation Operations*** requirements (if used)
  - Aerial observation criteria are defined and communicated.
  - Aerial ignition systems operations procedures are established.
- ☐ ***Air Quality Monitoring*** requirements (Appendix G):
  - Monitoring locations are identified.
  - Personnel and equipment are assigned.
  - Monitoring frequency and reporting times are established.
  - Action criteria are established.

- QA/QC issues are addressed.

- ☐ ***Post-Burn Activity*** requirements (Appendix H):

  - Safety for collection unburned oil or burn residue is assessed.

  - Evaluate possible damage of leaving unburned oil or burn residue vs. potential damage from machinery and foot traffic to recover oil and/or residue (marshes, deserts, and tundra could be particularly susceptible).

  - Evaluate potential for collection of unburned oil into sufficient quantity for another burn.

  - Appropriate equipment is identified (examples below):

    - On open or flowing water, collection using rakes, nets, skimmers, and/or sorbents are suitable for heavier oily burn residues.

    - Arrange interim storage capacity if needed.

  - Disposition of recovered unburned residue is arranged (waste disposal permits and transport).

  - Criteria are established for documentation of operational data, pre- and post-burn conditions. Assess the benefit for a re-burn.

  - To enhance recovery of marshes, avoid flooding post-burn.

- ☐ ***Demobilization Component*** has been prepared, reviewed, and approved.

  - Includes provisions for an After Action Review.

Final Pre-Burn Checklist for Field Command

Action	Completed?
Are ALL planned operations personnel and equipment on-site, available, and functional, including air support?	
Have the Site Safety and Ignition plans been verbally briefed to ALL personnel?	
Has each worker been briefed on burn objectives, their assignment, safety hazards and mitigations, escape routes, and safety zones?	
Are ALL permits and clearances obtained and available?	
Has ALL vulnerable infrastructure in the area been identified (*on land*—power lines, underground utilities, and structures; *on water*—bridges, docks, and marinas)? • Locations of all transmission lines are communicated to air resources. • Escape routes, ISB locations, safety zones, Incident Command Post, and staging areas should not be under or near power lines. • Protection is in place for all vulnerable infrastructure.	
Are current and projected weather forecasts favorable?	
Are ALL smoke-management specifications met?	
Are ALL emergency contingency resources available: either staged or on standby?	
Can undesirable, secondary fires be avoided?	
Are ALL necessary communications possible?	
Have ALL the required notifications been made?	
Have ALL the pre-burn conditions of approval been completed or addressed?	
In the ISB field commander's (Burn Boss) opinion, can the burn be conducted safely, according to plan and will it meet objectives?	

Habitat-Specific ISB Information

Upland Areas Including Forests, Fields, Prairies, and Savannas

While natural fires are often common in native grasslands, they are typically low intensity and fast moving. ISB can produce slow-burning, intense, sustained fires and therefore can be more damaging to plant roots, rhizomes, and organic soil biota. Most grass and sedge species recover better when ISB is conducted during the dormant season and when the soil is wet.

ISB may damage vegetation less in eastern tall grass prairie grasslands (e.g. Bluestem), than in central and western short grass prairie (e.g. Grama or buffalograss). Generally bunchgrass species are more fire sensitive than low-growing, rhizomatous grasses.

Woody shrubs, while they look similar to trees in many respects, are often not as fire sensitive. Many species are very fire tolerant. Shrubs are usually top-killed by fire, but may recover quickly by sprouting from underground.

Burns in winter tend to result in less damage, while burns in spring and summer tend to result in higher mortality to larger plants and hardwoods because of their increased susceptibility to stress. Although higher moisture levels can make ignition more difficult, this condition diminishes impacts due to heat from a burn. Greater impacts to vegetation in forested areas are typically the result of burning during dry seasons, when a fire is more likely to burn deeper into organic soils and damage roots. Spring and summer burns are more likely to result in changes to species composition; some species are promoted by burning and tend to grow vigorously after a burn, outcompeting the less fire-tolerant species.

Generally, ISB in forested areas should be discouraged. If not killed by fire, most species of trees take a long time to recover to pre-fire levels relative to faster-growing shrubs and grasses. Furthermore, wounds caused by fire can leave trees open to infection and insect attack. However, ISB may be reasonable for open or savanna-like forest communities, especially if the tree species are at least moderately fire tolerant. If ISB is done in forested areas, over story mortality can be minimized if there is high soil moisture and if decaying leaves, branches and oiled debris can be raked away from the base of high value trees.

Oil in a tree-lined stream can be moved downstream by flushing to an open area before burning. Soil heating and root damage can also be reduced by judicious use of ignition patterns. Further information the effect of fire on specific species can be found in the U.S. Forest Service Fire Effects Information System website at the following URL http://www.fs.fed.us/database/feis/.

ISB on high organic content soils such as peat can result in smoldering that persists for several days. Operational planning should consider this possibility and an extended presence to monitor such situations. Flooding dry soils, including peat, to float surface oil prior to burning, could be a possibility and would limit burning of unoiled soils and insulate soils from the heat from a burn.

ISB of Oil Seeping into a Trench

Photo courtesy of BP/Amoco.

Freshwater Wetlands

Many well-documented, marsh burns have been conducted around the world and have provided information on protecting marsh plants and the best time of year to burn. The roots of marsh plants, which contain the propagating portion for growth, are sensitive to heat. If burning is conducted at a dry time of year, such as in late summer, these roots can be killed if the heat is high enough and stays high long enough. Research has shown that some soils can be water saturated to the soil surface while others only need water levels to exceed 2-mm depth to provide sufficient heat protection to plant roots.

Flooding is a useful technique for flushing oil out of a marsh while protecting the roots of marsh plants from exposure to oil. When burning in marshes, responders should take care to prevent damage to shrubs and trees that grow in the rear, and higher elevations of a marsh.

Peat bogs are soils with high organic content. Peat burns are of concern where the water table is low and peat is dewatered. Its highly permeable nature could allow oil to penetrate deep into dry peat during a burn, such that the peat itself could ignite and burn beyond the target, oiled area. Saturated bogs are of less concern for fire control. In some cases, it may be possible to flood an oiled bog to float the oil, limit the potential for peat combustion, and the burn oil from the water surface.

Organic soils typically have low oxygen and nutrient levels, so degradation rates of oil residue would likely be very slow compared to a burn in other habitat types. Conversely, oil spills in peat areas are typically difficult to clean by either manual or mechanical methods, making ISB a viable option to minimize overall impacts.

Open Water Lakes and Ponds, Without Currents

Typically, burning floating oil on a water surface requires that oil be collected into slicks a minimum of 2–3 mm thick and then ignited. Oil is typically collected in fire-resistant booms towed through the spill zone by watercraft, or collected by natural barriers such as a shoreline.

In large lakes, a boom can be towed at 3/4 knot or less during the burning process in order to maintain the proper oil concentration or thickness. Usually the towboats move against the wind.

In small lakes and ponds, the body of water may be too small or shallow to tow a boom. Wind or mechanically generated currents—i.e. from a vessel's propeller (prop wash; known as mechanical herding)—can be effective for collecting and concentrating oil along a shoreline or in a stationary boom attached to a shoreline.

Surface collecting agents (also called chemical herders) are agents applied around the periphery of a spill on water to limit spreading and possibly even thicken an oil slick. Use of such agents may require various regulatory approvals. In the U.S., surface collecting agents are listed on the EPA National Contingency Plan Product Schedule (40 CFR 300 Subpart J http://www.epa.gov/osweroe1/content/ncp/product_schedule.htm).

Open Waters, with Current

Current can pose ISB control issues that should be carefully considered so as to preclude unintended consequences such as burns extending to downstream areas of greater sensitivity. Refer to API Technical Report 1252, *Field Operations Guide for In-Situ Burning of Offshore Oil Spills* for more information.

As mentioned above, burning floating oil on the water surface typically requires that oil be collected into slicks a minimum of 2–3 mm thick, and then ignited. Oil is typically collected in fire-resistant booms that are towed through the spill zone by watercraft, or collected by natural barriers such as a shoreline.

In large rivers, a boom may be towed at 3/4 knot or less relative to the current during the burning process to maintain desired oil concentration or thickness. This often means tow boats are moving in the direction of the current, but at a speed less than the current.

In rivers and small streams, oil carried by currents may be collected and concentrated in stationary booms attached to a shoreline or other permanent structures (e.g. pilings). If oil is near a shoreline, then booms can be used to divert oil to an area where it can be burned. Diversion booms can be positioned at an angle relative to a current, that is large enough to divert oil, but not too large that the current would cause the boom to fail. Oil can be contained behind a boom to speeds of about 3/4 knot. Above this, entrainment will cause loss of oil under a boom. Booms may be held in place by anchors, towing vessels, or lines that are secured to a shoreline. See *Oil Spill Response in Fast Currents—A Field Guide,* USCG 2001 or *Oil Response in Fast Water Currents: A Decision Tool*, USCG 2002, for details.

Cold Climate Considerations

The burning of oil under cold conditions, especially in the presence of ice, presents unique challenges for

- responders having to work with low temperatures,
- potential need for ice-strengthened vessels,
- potential for slicks to be accessible only in ice leads, and
- possible operations in remote locations (e.g. the Arctic) with periods of low visibility, even months of complete darkness.

While these conditions can hamper operations, they often provide favorable weathering conditions resulting in slower oil slick spread rates, the natural containment of oil by ice, and the encapsulation of oil in ice. Spilled oil can be frozen in place thereby retaining its fresh volatile properties for subsequent efficient burns, recovery at a later time, and possibly even treatment with chemical dispersants.

Ice Conditions on Water

Burning may be the only practical response option in ice conditions. Natural containment of oil can occur in some ice conditions because ice can inhibit the spreading and weathering of oil. At higher ice concentrations, oil spreads slower than on open water. When ice is less concentrated, spreading can still be reduced by the effect of wind herding against natural ice dams or by the judicious use of mechanical or chemical herding (discussed above). When ice concentrations cover more than 60% to 70% of the water surface, the ice floes pack together closely and provide a high degree of natural containment. As ice concentrations decrease, oil spreading increases until it reaches close to an open-water thickness in drift ice of 30% coverage or less. At higher ice concentrations, the oil spreads slower than on open water.

ISB in Snow and on Ice

Photo courtesy of NOAA.

Oil trapped under ice in lakes, ponds, streams, and rivers can be recovered using ice slotting to provide an opening through which oil can come to the surface. Slots can be cut in ice at least twice as wide as the ice is thick, and as the oil flows to the slots and accumulates, it can be ignited. In flowing water, the slots should be angled at about 30 degrees to the current for velocities of 1–4 knots. Tests have shown that over 90% of oils released upstream can be recovered. Diversion of oil beneath ice towards a collection area can be achieved by creating narrow slots into which wood or metal sheets that intend beneath the ice are inserted

Tundra

ISB can be used to volatilize and oxidize residual contaminants from vegetation after other response tactics have been used. Burning is especially useful for light coatings on leaves of sedges and grasses elevated above a tundra surface. Typically, one worker uses a metal rake to orient oiled leaves and stems more or less vertically. A second worker uses a weed burner, which consists of a flame nozzle, hosing, and a propane tank. The flame nozzle is held just above the contaminated vegetation until the vegetation is burned down to stubble. Burn residue can be recovered with hand tools. The benefit of recovery in tundra areas should be carefully weighed against the potential for causing additional physical damage.

The risk of damage from burning is relatively modest in moist and wet tundra which is dominated by sedges. Much biomass of these plants, including the buds from which new leaves sprout, is deep enough to be protected from the heat of a burn. Use caution in drier tundra where shrubs, mosses, and lichens are abundant because this vegetation has little or no ability to sprout from below ground.

Igniting Oiled Tundra from a Plywood Platform

Photo source: Alaska Clean Seas.

Inundated or wet tundra is subject to compaction damage; plywood sheets are often used to create working platforms to avoid trampling oil into the substrate.

Using ISB to remove pooled product from the ground surface in tundra that does not have standing water poses certain risks. The relatively large amount of heat required to burn pooled product in these areas could cause vertical migration of oil into the fragile root zone. Large, long burns could possibly induce some permafrost thawing in underlying tundra soils.

Deserts

Plants in desert areas are adapted to dry environments. Generally, larger plants are more likely to survive a wildfire. Cacti and other succulent plants do not usually combust and are more likely to be damaged when surrounded by dense herbaceous growth that burns. Surface soils in desert areas often consist of biological soil crusts containing highly specialized communities of cyanobacteria, mosses, and lichens. These crusts are formed by living organisms and generally cover those soil spaces not occupied by vascular plants. Crusts may be 70% or more of the living cover. Desert soil crusts are fragile and more susceptible to compaction disturbance caused by trampling, heavy equipment, etc. than to heat alone. ISB should generally be limited to areas devoid of vegetation, such as open spaces, between plant groupings or in seasonally dry streambeds. Soil crust can recover from fire effects; the degree of any damage depends upon soil moisture, as well as the intensity and duration of fire heat radiated downwards.

Appendix A
Appropriateness of ISB

A primary objective for spill response is rapidly removing oil and thereby limiting the magnitude of adverse environmental consequences. Good response decision-making means choosing the least environmentally damaging and most effective response option when a spill occurs. The negative event, the spill, has already occurred and response efforts are focused on ameliorating consequences.

In some situations, other response options are not effective or may cause more damage:

- Flushing often does not remove oil adhered to vegetation. Therefore, another cleanup tactic may be required to reduce the likelihood of additional environmental or human exposure.

- Burning oiled vegetation can limit the potential for wildlife exposure, as well as the movement of oil to other areas.

- Intrusive cleanup activities (e.g. construction of access routes, vehicle traffic, foot traffic, blockage, diversion of water flow) contribute to overall negative effects from response at a location.

An ISB can be a much less intrusive and less mechanically damaging option for removing free oil and oiled vegetation. The time window of opportunity for ISB can vary depending on the weathering state of the oil and local conditions. In some cases, there window of opportunity can be quite long (months).

Depending on exposures, components within oil can cause some acute and chronic effects to vegetation. When oiled vegetation is burned before the oil soaked into soils and exposed plant roots, the quality and speed of recovery has been observed to be enhanced. Although burning will not reduce effects from oil exposure that occurred prior to a burn, it can be very effective at reducing the extent and degree of additional effects by quickly and efficiently removing remaining oil. Many types of vegetation (e.g. prairies) have evolved to withstand periodic, naturally occurring wildfires.

Major Advantages and Disadvantages of ISB	
Advantages	**Disadvantages**
Allows rapid removal of oil and more complete removal from difficult to access locations; may be less damaging to the environment than other removal options.	Creates a smoke plume.
Typically requires fewer response resources than most other techniques.	Requires minimum oil thickness to burn, so may require containment.
Minimizes the amount of waste for handling and disposal.	Fire may be difficult to control.
Significantly reduces volatile emissions, and reduces response worker and wildlife exposure to emissions.	Residues may contaminate soils or sediments.
Can be used in many situations: on land, shorelines, on snow, on ice, etc.	

There are four main drivers for considering the use of in-situ burning:

1. Minimizing the spread of spilled oil on a land or water surface.

2. Rapidly removing surface oil to limit exposure time.

3. Reduced logistics and access constraints and reduced environmental damage compared to the use of other response options.

4. Minimizing the volumes of recovered oil that would otherwise need to be handled, transported, and treated; each activity has associated hazards.

Minimizing the Spread of Oil

Oil should be removed from an area quickly to prevent its spread and/or to limit exposure to sensitive sites. Burning can remove oil in minutes to hours to help prevent spreading, whereas manual or mechanical methods can take days to months. Response timing can become critical during certain seasons or in rapidly changing weather/water conditions. For example,

- Forecasted rain is likely to flush oil from a spill site into sensitive or previously unoiled areas;
- Temporary containment structures could fail; or
- Oil, held in a small area by snow and ice dams, could spread widely during a period of thawing.

Rapidly Removing Surface Oil

Effects from oiling are a function of concentration and time. ISB has high removal efficiency, which can greatly shorten exposure times for animals and plants and reduce the concentration of remaining oil. Where incomplete combustion is observed, the potential for a repeat burn can be considered.

Use of trenching or other means to gather surface oil before burning can aid removal efficiencies by creating thicker slicks. Oiled vegetation can be cut, gathered, and burned. In cases when burns are executed during dormant seasons, next year's vegetative growth could be minimally affected.

Reduced Logistics and Access Constraints

Spilled oil can spread into sensitive and/or inaccessible areas. Conventional recovery techniques can cause unintended environmental damage (e.g. trampling oil into substrates, mechanical damage to fragile plants and habitats via foot traffic, heavy equipment, dragging hoses, etc.). It can be very challenging to provide safe yet efficient access for people and equipment during a response. Burning can significantly reduce the oil while incurring much less environmental damage than conventional mechanical or manual recovery.

Minimizing Waste

Options for temporary storage, handling, transportation, and disposition or disposal of recovered oil and oily wastes can be limited, so the amount of waste generated should be minimized, if possible. *In-situ* burning can be up to 98% efficient at removal for the volume of oil encountered based on empirical observations from laboratory, meso-scale and field burns.

During both manual and mechanical cleanup, large volumes of recovered oil and oily waste can be generated. Those materials need to be properly and safely handled, which means coordinating temporary storage sites and interim treatment, transportation for any further treatment, and eventual recycling or disposal. Each of these activities has hazards. The remoteness of a site and associated transportation distances for recovered oil and oily wastes from approved disposal facilities should be a factor in a decision to burn.

Appendix B
Personnel Safety

A Site Safety Plan should be developed specifically for an ISB operation. It can be a stand-alone plan or an attachment to the overall Site Safety Plan for an incident. The Site Safety Plan must be communicated to all affected personnel prior to a burn. It should address the following at a minimum:

- PPE required by the role of each person (at a minimum, any field personnel should wear fire-resistant clothing, steel-toe leather boots, leather gloves, safety glasses, hard hat. Protective bunker gear (suitable for firefighting) may be required for personnel working closest to a fire). For any on-water response, field personnel should wear personal flotation devices and adjust gloves and boots to suit.

- Requirements for proper hydration, food, and rest periods.

- Heat stress and cold stress management.

- First Aid/medical procedures.

- Hazards of chemicals involved in the burn (oil, foam, herding agents, ignition agents, particulates, etc.).

  NOTE: LEL meters do not detect toxic hazards.

- Other site hazards (terrain, water, animal hazards, insects, etc.).

- Hazard Monitoring plan/Air Monitoring Plan/Exposure Limits.

- Site communications.

- Safe work procedures.

- Emergency procedures.

- Site map.

The United States Coast Guard has a template for comprehensive site safety plans for oil and hazardous materials response that uses the ICS form approach. It can be found at:
http:/www.uscg.mil/forms/ics/ICS_208_CG.pdf

Appendix C
Weather and Smoke Management

Wind (strength, altitude, and direction), precipitation (type and severity), temperature (air and surface), the presence of ice or snow, soil saturation (water and/or oil), and other climatic conditions can affect whether oil can be ignited and a burn sustained. These conditions can influence the conduct of a burn and the safety issues to be addressed.

The temperature of the surface on which an oil is spilled has a greater influence than air temperature. Temperature will affect the viscosity and therefore the spreading of oil. It also affects the volatility and therefore the ease of ignition.

Red Flag Conditions

Operations on land should consider the fuel value of vegetation that might be accidentally ignited during an ISB. Any of the following conditions make ISB more likely to result in unintended areas being burned:

- Wind gusts are >40 mph (35 knots or 65 km/hour).
- Relative humidity is < 20 %.
- Air temperature is > 80°F.
- Cold front expected to pass within 12 hours.

INDICATIONS OF CHANGING WEATHER CONDITIONS

Responders should be especially attentive to changing conditions, which are indicated by the following:

- Approaching cold fronts are forecasted.
- Cumulonimbus cloud development.
- Sudden calm wind observed.

- Shifting winds are experienced.

- Lenticular clouds or high, fast-moving clouds seen. (Lenticular clouds are a sign of high winds aloft—if they surface they could severely impact the safety of field and aviation personnel, as well as greatly alter fire behavior.)

Changes in any of these conditions during a burn could indicate a possible fire control concern and could trigger actions to move personnel and equipment or to terminate a burn. A Burn Plan should reflect such contingencies.

EFFECTS OF ATMOSPHERIC STABILITY

Atmospheric stability has a major effect on the dispersion of ISB plumes. Turbulence increases the entrainment and mixing of unpolluted air into a plume. Solar radiation also causes rising columns of air (thermals) to form naturally when the air over darker surfaces becomes warmer and then rises relative to the colder air over more reflective, adjacent surfaces. The rising thermals of air carry a smoke plume aloft, reducing ground-level exposure. Strong solar radiation and low wind speed provide the best conditions for atmospheric turbulence, as shown in the table below. Stability classes A through C are preferred for ISB. The effect of atmospheric stability and dispersion must be considered relative to the scale of a burn. Small burns and remote locations may be acceptable in less favorable conditions. The effect of atmospheric stability and dispersion must be considered relative to the scale of a burn. Small burns and remote locations may be acceptable in less favorable conditions.

Solar radiation has less of an effect near dawn and dusk (< 15 degrees from the horizon), such that during certain times of the year the hours in a day potentially available for the preferred conditions may be limited. In general, burning during night hours is less advisable because the potential for a dense cloud of smoke forming at ground level increases.

Pasquill-Turner Atmospheric Stability Classes and In-Situ Burning			
Better for ISB		**Caution for ISB**	
STABILITY CLASS	DEFINITION	STABILITY CLASS	DEFINITION
A	very unstable	D	neutral
B	moderately unstable	E	slightly stable
C	slightly unstable	F	stable

Conditions that Define Pasquill Stability Classes						
SURFACE WINDSPEED		DAYTIME INCOMING SOLAR RADIATION			NIGHTTIME CLOUD COVER	
m/s	mi/hr	Strong	Moderate	Slight	> 50%	< 50%
< 2	< 5	A	A–B	B	E	F
2–3	5–7	A–B	B	C	E	F
3–5	7–11	B	B–C	C	D	E
5–6	11–13	C	C–D	D	D	D
> 6	> 13	C	D	D	D	D
Class D applies to heavily overcast skies, at any wind speed day or night, or when the sun is within 15 degrees of the horizon (dawn and dusk)						

Under calm winds, a smoke plume may rise high in the air, depending on atmospheric stability. A high-rising smoke plume, typically associated with reduced wind speeds, should reduce overall public health risks from the plume's particulates. Lower wind speeds also allow better fire control. However, with very calm winds during a large burn, the potential exists for a cloud of dense smoke to form near the ground, especially on overcast days. This potential increases at night.

The potential for atmospheric inversions should be considered. While unlikely to occur, atmospheric inversions could trap a smoke plume near the ground, leading to potential exposure concerns for responders and the public. Low lying smoke can cause safety hazards on roadways.

Smoke Plume Lofting from an ISB in Area of Mixed Vegetation

Photo courtesy of Minnesota PCA.

WEATHER SERVICE ASSISTANCE

Government meteorologists are often available locally and can usually provide a spot forecast. In the United States, the National Weather Service (NWS) maintains a fire weather webpage where local fire weather forecasts can be obtained and spot forecasts for specific locations can be requested. http://www.srh.noaa.gov/ridge2/fire/ is the current webpage. The specific webpage URL seems to change occasionally so a search from http://www.weather.gov may be necessary.

Appendix D

Fire Containment & Fire Safety

FIRE-RESISTANT BOOMS

When oil spills on water are confined with booms to contain oil or increase the spill thickness for ISB, the booms should be fire-resistant. Intrinsically fire-resistant booms are made of fire-resistant materials like ceramic-faced cloth or stainless steel tanks. Another type provides fire resistance through the use of water pumped through the boom to dissipate heat.

There are three main types of fire boom:

- Fence-type boom with silicone-coated refractory fabric, aluminum connectors, and stainless steel floats with glass foam.
- High-temperature ceramic and stainless steel covers with a solid flotation core.
- Water-Cooled Fire Boom.

More detail is provided in Appendix D of API Technical Report 1252, *Field Operations Guide for In-Situ Burning of On-Water Oil Spills*.

FIREBREAK CRITERIA

Spills on land often are naturally contained, but dikes can be constructed using earth-moving equipment to contain oil or act as firebreaks. Firebreaks are an important component of every burn. Not only can the oil burn but, depending upon conditions, certain natural vegetation can burn as well. The table below describes minimum recommended dimensions of firebreaks depending on site conditions. Firebreaks can be natural features and roads, or they can be created by mowing or tilling. Firefighting equipment can be used to wet a perimeter for fire control and will be needed in most cases to extinguish a large fire if it gets out of control.

FIREBREAK DIMENSIONS FOR NON-FORESTED LAND			
TYPE OF VEGETATION	MINIMUM FIREBREAK WIDTH (FEET)		
	Upwind	Downwind Side	Downwind Flank
Non-volatile Herbaceous (green grasses having low wax, oils, resins such as Big bluestem, Kentucky bluegrass, and Smooth bromegrass)	20	20	20
Volatile Herbaceous (dead plant matter and grasses having high waxes, terpenes, oils, or resins such as Switchgrass and Lovegrass)	20	40	30
Non-volatile Woody (hardwood trees such as elms, Russian olive, and honey locust; also invasive shrubs such as sumac, snowberry)	20	60	50
Volatile Woody (coniferous softwood trees such as eastern red cedar and ponderosa pine)	40	300	100

Natural Resources Conservation Service (Sep 2012)
Firebreak Design Procedures (394DP)
http://efotg.sc.egov.usda.gov/references/public/NE/NE394DP.pdf

Tilling for a Bare Soil Fire Break

Photo courtesy of eXtension, associated with U.S. land-grant universities.

SMOKE AND ELECTRICAL TRANSMISSION LINE HAZARDS

Dense smoke can conduct electricity between overhead high voltage transmission lines resulting in shorting or grounding. Even less dense smoke particles can coat insulators over time and result in shorting to ground. ISB effects to high voltage transmission lines should be avoided and line operators notified. Keep personnel and equipment at least 100 ft from the surface location under the outermost transmission line.

FOAM AS A FIRE CONTROL FOR POOL FIRES

Large and deep pools of oil may generate radiative heating from sustained burning that is not controllable with firebreaks and berms alone. Consideration should be given having a capability to extinguish such pool fires using fire-fighting foam. Keep in mind that such foam use is an all or none proposition. Enough foam capability has to be in place before application to totally cover the fire or the attempt will fail and the fire will destroy the applied foam. For example, a (100 ft × 100 ft =) 10,000 sq. ft pool of oil greater than 1-in. depth and a foam concentration of 3%; the calculated amount needed to extinguish a fire is 3,120 gallons of foam and 100,880 gallons of water. With an oil depth of less than 1 in. the amounts would be 450 gallons of foam concentrate and 14,550 gallons of water.

Foam application requires special equipment (i.e. eductors or mixing tanks, and specific hose nozzles). Foam calculators for smartphones are readily available. Use of foam requires sufficient access to the oil pool by heavy equipment in order to deploy the foam.

EFFECTS OF COMBUSTION HEAT ON SPILL RESPONDERS

In-situ burning of oil produces large amounts of heat, which is transferred into the environment through convection and radiation. About 90% of the heat is convected into the atmosphere. The remainder is radiated from the fire in all directions. Heat radiated outward towards responders can be a cause of heat exhaustion and burns to unprotected skin. Of lesser concern is heat radiated downward, which might affect soil or water column resources.

Safe Approach Distances for In-Situ Oil Fires	
Exposure time	**Safe approach distance for personnel (fire diameters)**
Infinite	4
30 min	3
5 min	2

Source: Buist et al., 2003.

The potential for causing injury to exposed workers is a function of both the level of heat and the duration of exposure. Wood will char if positioned about half a fire diameter from the edge of a burn. The safe approach distance to an in-situ oil fire is from two to four times the diameter of a fire, depending on duration of exposure, as shown in the table below. Conservatively, it is assumed that a safe approach distance to the edge of a burn is approximately four fire diameters.

It is important to recognize that the oil contained in a towed boom is relatively thick in the early stages of a burn and that this thickness is maintained by towing or holding vessel position relative on oncoming current. If the towing was to stop or slow or the boom was to break, then this thick layer would spread quickly to cover an area several times that of the previously boomed oil. This will increase the fire diameter, the heat flux from a fire, and the need for responders to move further away to avoid injury or discomfort.

Appendix E
Ignition of ISB

The primary equipment needed to burn on land is an ignition source. In general, an ignition device must meet two basic criteria to be effective: provide sufficient heat to produce enough oil vapors to ignite and then keep burning; and it must be safe to use. Ignition sources range in sophistication from matches to Helitorch (ignited gelled fuel dispensers) suspended under helicopters.

- Propane or butane torches and weed burners have been used to ignite oil, but such compressed gas torches tend to blow thin oil slicks on water away from the flames. They work better with thick, contained oil.

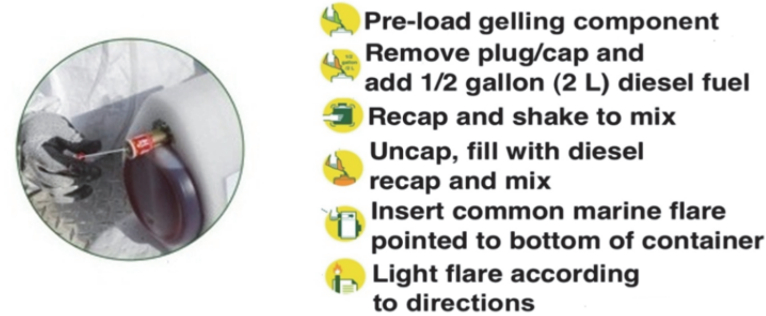
- Fuel-soaked rags or sorbent pads can also be used for ignition. Diesel is more effective as a fuel than gasoline because it burns longer and thus supplies more sustained heat to the oil. It is also less volatile and much safer to use.

- Quart bottles of gelled gasoline or diesel, which are taped to a flare, have been used for on-water ignition. Delay fuses are a desirable safety feature.

Oil Ignition with a Weed Burner

Photo source: API Publication 4724.

- A drip torch containing a 70:30 diesel-kerosene (or diesel-gasoline) mixture is often used for vegetation and soils accessible by foot. In warm weather, a 60:40 ratio is recommended. The drip torch consists of a fuel reservoir, a breather valve to allow air in when the fuel is exiting, and a tube to deliver fuel to the igniter. The igniter is a wick that serves as a continuous flame to ignite drops of fuel, which fall as the torch is tilted toward the ground.

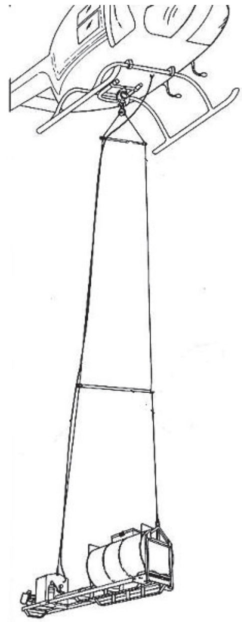


Courtesy of BP.

- Another hand-made device that can be floated into oil contained by a boom is a marine flare taped between two plastic jugs to provide flotation.

- For weathered oil, a sorbent (polypropylene) boom coiled and soaked with diesel can be used with the igniter placed on top.

- Commercial handheld ignition devices for ISB may be available. These tend to go into and out of production frequently. Elastec and DESMI-AFTI have recently manufactured them. An Internet search is probably the best approach to finding those that are currently available.



Source: USDA.

- Originally designed and used for forest fire response, the most sophisticated commercial devices used today for igniting oil spills are the Helitorch igniters. These are helicopter-slung devices that emit a stream of burning, gelled fuel and produce an 800°C flame that lasts up to 6 minutes. The stream of burning gelled fuel breaks up into individual globules before hitting the oil spill. A commercial gelling agent (e.g. Fire-Trol, SureFire, Petro Jel, and Flash21) is often mixed with gasoline, diesel, or crude oil to produce the gelled fuel used in these devices. Helitorch igniters were developed for the forest industry and are commonly available with a 110 to 1100 L (30 to 300 gal) fuel tank capacity.

- Another aerial ignition system commonly used for wildland prescribed burns is the plastic sphere dispenser (PSD). This machine ejects polystyrene spheres of 1.25 in. diameter containing potassium permanganate onto the area to be burned. It injects ethylene glycol into the sphere just before ejection from the device. An exothermic reaction provides a reliable ignition and a time delay of at least 20 seconds. The spheres burn for a shorter period of time than gelled fuels. From a logistical, safety and hazardous materials handing standpoint, PSDs are less complicated than a helitorch. Use on water is not usually successful because the components are water soluble.

- Flame spread rates are affected, as follows, in quiescent conditions:

  - As oil weathering increases, ignition time increases.

  - Ignition times decrease with increasing slick thickness.

  - Increasing viscosity reduces flame spread rates at a constant thickness and flash point.

Research and development is ongoing to develop improved high-speed ignition systems for deployment from fixed wing aircraft platforms.

If possible, it is often advisable to conduct a limited test burn to confirm ignitability under prevailing conditions. Weathered and/or emulsified oils may require initial thicknesses of several millimeters as well as larger than normal ignition areas. High soil and atmospheric moisture levels may influence ease of ignition. Test burn observations can indicate that it may be beneficial to:

- Use two or more hand-held igniters per ignition operation;

- Use a hotter and long-lasting igniter; or

- Momentarily hover with a Helitorch (to produce a larger ignition area).

Appendix F

Efficiency and Volume Estimation

Calculations of burn efficiency provide a means to determine whether a repeat burn may be appropriate, for performance assessment, and to improve conduct of burns. Burn efficiency is measured as the percentage of oil removed compared to the amount of residue left after a burn. If the quantity of hydrocarbon vapor from a spill is too low, then a burn will not continue to heat more oil for vapors and a burn will self-extinguish. The amount of vapor produced during a burn depends on the degree of heat radiated back to the oil.

For oil spills on water or other relatively even and flat surfaces, Efficiency (**E**) can be calculated by Equation #1.

Equation #1 $$E = \frac{V_i - V_f}{V_i}$$

Where

V_i is the initial volume of oil that was burned,

V_f is the volume of residual oil remaining after burning.

The initial volume of oil, **V_i**, may be known from inventory measurements. If that is not available or reliable, then the area of an oil slick can be estimated visually using objects of known dimension (e.g. a response vessel or a structure) or using timed over-flights, aerial photographs, or remote sensing. The surface area of the spilled oil can be multiplied by an estimate of average slick thickness to yield an estimated slick volume. Thickness can be estimated by taking samples, visually using objects of known dimension, or by remote sensing.

The volume of residual oil remaining after burning, **V_f**, can be estimated by observation in the same manner. If residue remains, it can be recovered either by skimmers or sorbents and estimated by measuring the volume or weight recovered. If residue cannot be recovered, its volume can be estimating in the same way as for the initial volume of oil. It should be noted that Equation #1 does not account for the volume of oil lost through soot released in a smoke plume produced during a burn, which is a small amount and difficult to measure, or any residue that has sunk or cannot be collected.

In terrestrial locations and where measuring average residue thickness on water is impractical, an approach to estimating burned oil volume is to use Equation #2 with a range of empirical burn efficiency coefficients.

Equation #2 $$V_i - V_f = A \times E \times T$$

Where

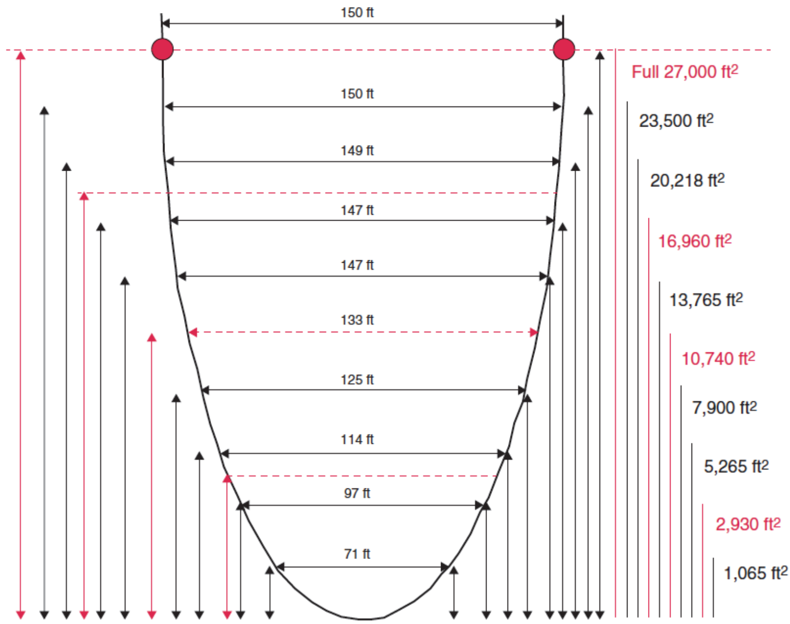
$V_i - V_f$ is the estimate of the amount of burned oil in gallons,

A is the area of burned oil in square feet,

E is the assumed burning efficiency rate (a range from 0.07 to 0.05 gallons/minute/square foot, and

T is the duration of the burn in minutes.

Minimum and maximum estimates can be determined using the coefficients.



Estimation of Oil Contained in 500 ft of Boom in a Catenary or "U" Configuration

Source: Al Allen.

Oil burns at a rate of about 3.7 mm per minute or about 100 gallons per square foot per day (ASTM F1788). The rate has been shown to be relatively independent of physical conditions and oil types. A catenary boom configuration continuously kept about 1/4 full will burn about 7,500 bbl in 12 hours.

Appendix G

Air Quality Monitoring

ISB primarily produces carbon dioxide (73%) and water vapor (12%), which are released to the atmosphere. Particulates commonly account for about 10% of the original volume burned. Gaseous compounds are emitted in minor amounts, including carbon monoxide (3%), sulfur dioxide (1%), and other compounds totaling less than 1%, which includes nitrogen oxides and PAHs. Typically, about half of the particulates in a smoke plume are from soot. Soot is responsible for the dark or black appearance of smoke and is composed of carbon and possibly incompletely combusted compounds.

Air sampling is not necessarily a requirement for the approval of ISB. Proximity to receptors and the scale of the burn are factors to be considered in the decision and permission process. However, real-time monitoring of emissions during an ISB provides continuous feedback as to whether the burn is progressing properly and safely. A well-planned monitoring program during which data are recorded before, during, and after a burn will also help answer any questions arising after a burn operation is completed. SMART (Special Monitoring of Applied Response Technologies) protocols provide guidance for rapid collection and reporting of real-time air-quality information to assist the IC with decision making. See http://response.restoration.noaa.gov/sites/default/files/SMART_protocol.pdf.

MONITORING OPERATIONS

SMART protocols recommend at least three monitoring teams for large-scale (Tier 2 and 3) burns. Each team uses real-time particulate monitors capable of detecting at least PM_{10}, if not $PM_{2.5}$. The instruments provide instantaneous readings of particulate concentrations, as well as a time-weighted average (TWA) over the duration of time that the instrument has been logging data. Each team should have a global positioning system (GPS) device, and other equipment for collecting, averaging, and documenting the data. In addition to automatic data loggers, manual recording should occur every few minutes and be reported through ICS channels at each new location and whenever a significant change occurs.

For smaller scale incidents, monitoring should occur at least downwind of the burn but upwind of population centers or other sensitive locations. If there is no potential for human exposure, air sampling using SMART protocols is not needed.

HEALTH ACTION LEVELS

The U.S. EPA has set human health standards for inhalation of soot, or particulate matter (PM). There are two particulate matter thresholds: PM_{10} and $PM_{2.5}$, which are parameters deemed protective for public exposure [National Ambient Air Quality Standards (NAAQS)]. The existing NAAQS exposure thresholds are designed for continuous sources such as industry and motor vehicle emissions. In contrast, in-situ burning will predominantly occur over a short period of time and as a single event.

Responders may use guidance provided by the U.S. National Response Team (NRT) to interpret the data and formulate recommendations. The NRT recommends a conservative upper limit of 150 µg of PM_{10} per cubic meter of air, averaged over 1 hour. This level of concern does not define a threshold between safe and unsafe conditions, but should be used as a general guideline. If it is exceeded substantially, human exposure to particulates may be elevated to a degree that justifies terminating a burn or moving responders or other personnel to a safe distance. However, if particulate levels remain generally below the recommended limit with few or no transitory excursions above it, there is no reason to believe that the population is being exposed to particulate concentrations above the EPA's NAAQS.

National Ambient Air Quality Standards for Particulate Matter				
Particulate Diameter (microns)	**Primary Standards**		**Secondary Standards**	
	Level	**Averaging Time**	**Level**	**Averaging Time**
PM_{10}	150 µg/m^3	24-hour (1)	Same as primary	
$PM_{2.5}$	15 µg/m^3	Annual (2) (Arithmetic Average)	Same as primary	
	35 µg/m^3	24-hour (3)	Same as primary	

Source: http://www.epa.gov/air/criteria.html

(1) Not to be exceeded more than once per year on average over 3 years.

(2) To attain this standard, the 3-year average of the weighted annual mean PM2.5 concentrations from single or multiple community-oriented monitors must not exceed 15.0 µg/m^3.

(3) To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 35 µg/m^3 (effective December 17, 2006).

CRITERIA FOR PARTICULATE MONITORS

- Rugged and portable: The monitor should be suitable for fieldwork, be able to withstand shock, and be easily transportable in a vehicle, small boat, or helicopter. Maximum size of the packaged instrument should not exceed that of a carry-on piece of luggage.
- Operating temperature: 15–120°F.
- Suitability: The instrument should be suitable for the media measured, e.g. smoke particulates.
- Operating duration: 8 hours or more.
- Readout: The instrument should provide real-time, continuous readings, as well as time-weighted average readings, in µg/m^3.

- Data logging: The instrument should provide data logging for 8 hours or more.

- Reliability: The instrument should be based on tried-and-true technology and operate as specified.

- Sensitivity: A minimum sensitivity of 1 μg/m^3.

- Concentration range: At least 1–40,000 μg/m^3.

- Data download: The instrument should be compatible with readily available computer technology, and provide software for downloading data.

Example of a Field-Deployable Particulate Monitor that Uses Light Scattering Technology

Photo source: USDA Forest Service.

Appendix H
Unburned Oil and Burn Residue Recovery

Collection of unburned oil and/or burn residue after an ISB is the primary post-burn activity. When the remaining unburned oil can be gathered to a thickness of at least 2–3 mm, a re-burn can be attempted. Follow the same process for re-burns as for the initial burn.

Eventually oil on soil or water will be of insufficient thickness and/or volatility to sustain burning. Studies have shown that residue contains fewer volatiles than the initial oil, but the heavier, less volatile constituents [such as poly aromatic hydrocarbons (PAHs)] remain in the same relative proportion as in the initial spill. Residue often has the composition and appearance of highly weathered oil of the same type.

Upon completion burning operations, burn residue should be collected and placed in suitable containers for subsequent transport to an approved storage site and ultimate disposal facility. Collection of residue after upland and shoreline burns involving sand, gravel, or road surfaces and some agricultural fields can be accomplished using tractors and graders. In other areas, manual collection using hand tools and sorbents can be preferred to minimize damage to surviving plant roots and soil ecology.

The unburned oil and/or burn residue which cannot be collected often serves as a carbon source for soil biota, which will then biodegrade the remains. Some residues can be almost chemically inert. However, if present in a thick layer then this could form a crust which retards degradation and revegetation unless broken up and worked into the soil surface. Applying soil amendments (fertilizer) for an appropriate balance of nitrogen, phosphorous, and potassium can enhance biodegradation.

Careful consideration should be given to the possible release of burn residue constituents without recovery. The benefits from collection should be weighed against the potential damage from responders and equipment used for residue collection. In some cases, plywood sheets can be laid as work platforms to limit trampling oil into soils or sediments.

- The residue of heavier oils can result in heavy residues which can sink in surface waters. Recovery can be possible using nets.

- Medium oil residues can form mats or sticky accumulations which can be recovered using manual tools.

- Lighter oils, that are still liquid, can be recovered using mechanical equipment and/or sorbents.

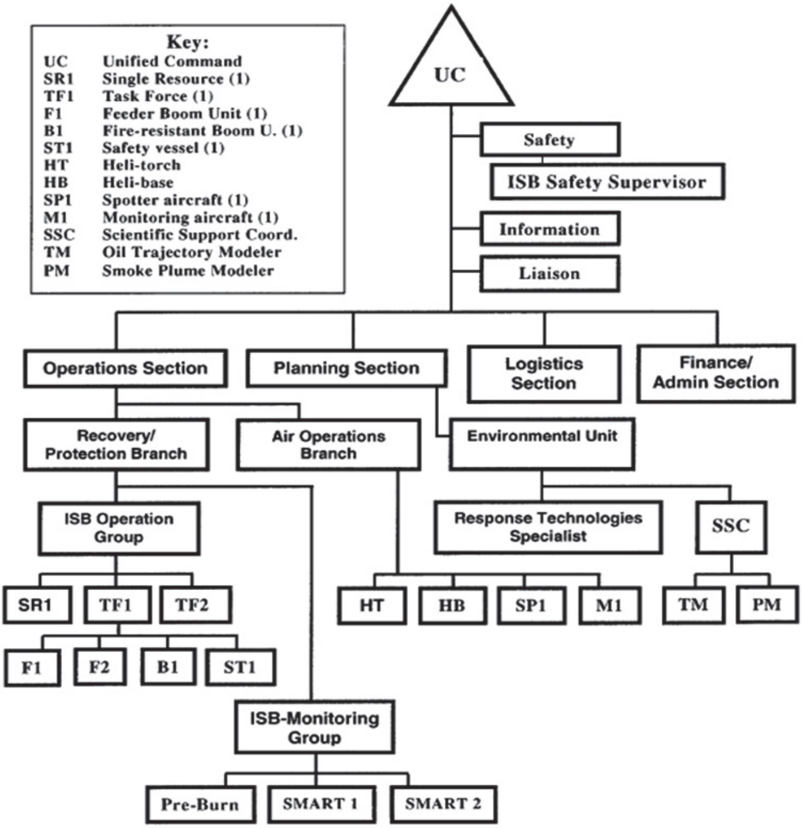
Studies have shown burns on water do not increase oil constituent concentrations in waters under a burn as compared to not burning. Thermocouple probes in the water during the Newfoundland Offshore Burn Experiment showed no increase in water temperatures during the burn. ISB may impact the water surface microlayer habitat, but circulation and organism replacement from adjacent and underlying waters result in very limited effects.

Appendix I
Incident Command for ISB

The command structure for the resources engaged in ISB operations should be clearly provided in an Incident Action Plan (IAP). The IAP should be developed and approved for the operational period in which the ISB operations are to be conducted, and should include an ISB Operations (or Burn) Plan specifically developed to address ISB operations. If it is a separate document, the Operations Plan should be clearly referenced in the applicable IAP.

In general, the ISB operations tactical resources consist of single resources or task forces following the Incident Command System (ICS). Task forces are created to accomplish specific tasks (e.g. create fire breaks around a designated burn area). The type and number of resources required will depend on the amount of oil to be burned, the area available for ISB operations, and the number of resources available.

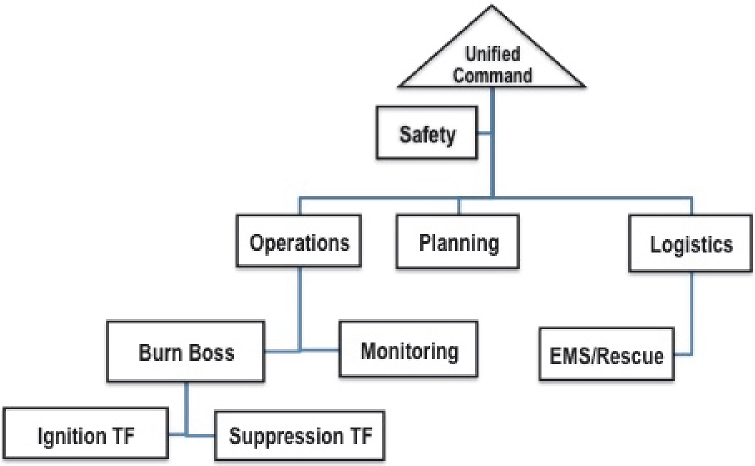
At a complex incident, these resources are usually organized into an ISB Operations Group that is supervised by an ISB Operations Group Supervisor. Span-of-control principles should be followed when creating the ISB Operations Group. The ISB Operations Group Supervisor reports to either the Operations Section Chief or to the Recovery and Protection Branch Director, if established for large incidents. If burn residue recovery is required, those assigned resources should be appropriately organized in the Operations Section. An example ICS organization for larger, complex burns is shown below.



Example of Larger ICS Organization for ISB

All aircraft resources, including aerial ignition platforms and monitoring helicopters, should be assigned to the Air Operations Branch and should support the ISB operations from that position in the ICS organization.

More typical for inland ISB, smaller/independent burns can be managed with a more compact organization, as shown below, as long as span of control limits are observed.



Example of a Smaller ICS Organization for ISB

SPECIALIZED ICS ROLES FOR ISB:

- **Burn Boss/Ignition Specialist/Firing Boss**: reports to the Operations Section Chief or Branch Director—This person is responsible for determining the ignition pattern to accomplish the objectives, when ignition should occur, and where suppression crews should be placed.

  This position has complete authority for and directs the firing operation, develops firing plan(s), performs the initial briefing from the firing plan, covers the assignments of each boss/supervisor (and pilot when using aerial ignition). This position also instructs the igniters/ignition team (or pilot) on the firing sequences and keeps them informed throughout the entire operation. For aerial Plastic Sphere Dispenser operations, this person is usually in the helicopter with the dispenser operator. For helitorch operations, the pilot is usually the only person onboard the aircraft.

- **Igniters/Ignition Team/Ignition Crew:** reports to the Burn Boss—Their primary responsibility is to ignite the burn under the Burn Boss's direction. They may also serve as a second suppression crew.

- **Fire Suppression Crew:** reports to the Burn Boss—This crew is responsible for patrolling downwind of a fire to check for spot fires and put them out. The Burn Boss should tell them where the greatest danger may be, but they should be aware that spot fires can occur anywhere. If the Suppression Crew finds a spot fire outside the planned burn area, all ignition is stopped until the spot fire is controlled.

- **Air Quality Monitoring Team:** These personnel collect visual and air quality data at locations specified in the burn plan and as directed during the course of a burn. They maintain communications with the Burn Boss and command post, relaying visual burn progress and analytical data (most likely particulate and perhaps vapor levels). They assure QA/QC of monitoring data and safety at the monitoring locations. They may collect long-term samples for later lab processing, if specified in the monitoring plan.

Consultation with personnel skilled in conducting prescribed fires is recommended for burning larger oil volumes of oil on land. State and federal land managers often use prescribed fire as a land-management tool. Prescribed fire practitioners can assist in evaluating potential impacts of a burn on vegetation and wildlife, as well as provide tactical assistance in planning and execution of burns.

For additional information on specialized ICS roles for ISB, please refer to API Technical Report 1253, *Selection and Training Guidelines for In-Situ Burn Personnel*.

Glossary

Term	Definition
Absorbent [the process is called absorption]	A material that picks up and retains a liquid distributed throughout its’ molecular structure causing the solid to swell (50% or more). The absorbent is at least 70% insoluble in excess fluid. (ASTM F726-99)
Accelerant (or promoter)	A volatile substance, such as diesel fuel or gasoline, applied on a weathered or viscous oil to provide initial vapor concentrations sufficient to ignite a burn.
Acute effects	Health effects which occur within minutes to hours of exposure.
Adsorbent [the process is called adsorption]	An insoluble material that is coated by a liquid on its’ surface including pores and capillaries without swelling more than 50% in excess liquid. (ASTM F726-99)
Atmospheric inversion	Usually refers to an increase in temperature with height in the atmosphere, which is opposed to the normal temperature decrease. It can suppress convection and trap polluted air near the ground.
Backfire	A fire set along the inner edge of a burn area boundary to consume the fuel in the path of the main burn and effectively increase the size of the boundary firebreak.
Boom	Floating, usually tubular, barriers for the containment, diversion, deflection and absorption of spreading liquids. Some boom has non-floating skirts that hang underneath to keep oil from slipping under the floating portion.
Bunker gear	Also known as turnout gear is outer clothing specifically designed for firefighters to provide thermal protection.

Term	Definition
Burn Boss)	A certified position for wildland firefighter who directs prescribed fire operations and oversees training and qualifications of prescribed fire staff and volunteers at the local level. See Appendix I.
Catenary	A curve formed by a perfectly flexible, uniformly dense and un-stretchable cable suspended by its endpoints.
Chronic effects	Sublethal health effects which occur within weeks to years after exposure.
Containment boom	A temporary floating barrier used to contain an oil spill.
Convection	Mixing of gas or fluid due to temperature differences.
Cumulonimbus cloud	A dense towering vertical cloud associated with thunderstorms, lightening, gusts, hail, and atmospheric instability.
Desert	A dry region of sparse vegetation where evaporative losses exceed precipitation.
Diversion boom/ deflection boom	Placing a boom in a body of contaminated water for the purpose of diverting the contamination to a collection point or away from a sensitive area.
Emulsion/ emulsified oil	The formation of a water-in-oil mixture. This occurs over time as the oil weathers and surface mixing occurs. Oil viscosity greatly increases making collection and pumping the emulsion very difficult. Some emulsions can contain up to 70% water and they can become stable and not separate unless heat or chemical demulsifiers are applied.
Entrainment	The loss of oil under a containment boom when it is pulled along by the water current passing below. Entrainment typically occurs from booms are deployed perpendicular to the water flow.
Fire boom	Fire-resistant boom. See Appendix D.

Term	Definition
Firebreak	A natural or constructed barrier used to stop or check fires.
Fuel load	The mass of combustible materials available for a fire, including vegetative materials and oil.
Herding agent [AKA, surface collecting agent]	A product that pushes or compresses an oil slick on the water surface by exerting a higher spreading pressure than the oil.
Helispot	A natural or improved takeoff and landing area intended for temporary helicopter use.
Helitorch	Helicopter-slung devices that emit a stream of burning, gelled fuel, often used to ignite prescribed burn wildland fires.
IC	Incident Commander is the person with overall responsibility for all aspects of an emergency response.
ICS	Incident Command System is a management system used for the command, control, and coordination of emergency response (required by law in the U.S.).
Lenticular cloud	Stationary lens-shaped clouds that form at high altitudes, normally in perpendicular alignment to the wind direction.
Lower explosive limit (LEL)	Lowest concentration of a vapor for a given material that will support combustion.
Marsh	A type of wetland that is dominated by herbaceous rather than woody plant species.
Oil sorbent	A material used to absorb oil but not water.
Particulates/ particulate matter	Tiny, solid matter which can be suspended in air.
Permafrost	Natural soil that stays at or below the freezing point of water for two or more years.

Term	Definition
Peat bog	An accumulation of partially decayed vegetation commonly containing Sphagnum moss, although many other plants can contribute. Peat forms in wetland conditions, where flooding obstructs flows of oxygen from the atmosphere, slowing rates of decomposition.
PM_{10}	Particulate matter with diameter of 10 µm or less that can penetrate the deepest part of the lungs such as the bronchioles or alveoli.
$PM_{2.5}$	Particulate matter with diameter of 2.5 µm or less, that tends to penetrate even further than PM-10 into the gas exchange regions of the lung.
PPE	Personal Protective Equipment refers to personal protective clothing, helmets, goggles, or other garments or equipment designed to protect the wearer's body from injury.
Poly aromatic hydrocarbon compounds [AKA, polycyclic aromatic hydrocarbons (PAHs) or polynuclear aromatic hydrocarbons (PNAs)]	Hydrocarbon compounds found in oil that consist of fused aromatic rings and do not contain other atoms of other elements. They are of concern because some have been identified as carcinogenic, mutagenic, and teratogenic with prolonged exposure.
Prairie	Land areas of moderate rainfall characterized by grasses, herbs and shrubs, rather than trees, as the dominant vegetation type.
Prescribed fire/ prescribed burn	Deliberately ignited fire for the purpose of forest or prairie management, often to remove heavy vegetative fuel buildup or simulate natural cycles of fire in an ecosystem. Also called a controlled burn.
Propeller wash herding	Movement of an oil slick using the hydraulic force of a boat engine propeller or bow wave to create a current in the underlying water.

Term	Definition
PSD	Plastic Sphere Dispenser (ISB ignition device—Appendix E).
Rhizomes/rhizomatous	A mass of underground plant roots that can spread and propagate new aboveground growth.
Savannas	Upland vegetated land area where trees are sufficiently far apart to not form a continuous canopy.
Sedge	Low-growing flowering plants often found in wetlands and areas with poor soils.
SMART protocol	Special Monitoring of Applied Response Technologies. A program for collecting monitoring data for ISB and dispersant use operations.
Sorbent	An insoluble material or mixture of materials used to recover liquids through the mechanisms of Absorption or Adsorption or both. (ASTM F726-99)
Strike Team	ICS term referring to specified combinations of the same kind and type of response resources, with communications, and a leader.
Task Force	ICS term referring to any combination or single resources assembled for a particular tactical need, with common communications and a leader. A Task Force may be pre-established and sent to an incident, or formed at an incident.
Tundra	A treeless area between the icecap and the tree line of arctic regions, having permanently frozen subsoil and supporting low-growing vegetation.

Term	Definition
UC	Unified Command is used when there is more than one party or agency with incident jurisdiction. Organizations work together through the designated members of the Unified Command, often the senior person from agencies and/or parties participating in the Unified Command, to establish a common set of objectives and strategies in a single Incident Action Plan.
Viscosity	Property of a fluid that resists flow.
Volatiles/volatile organic compounds	Organic (carbon) chemical molecules having a high vapor pressure.
Weathering (oil)	A combination of physical and environmental processes affecting oil such as evaporation, emulsification, dissolution and dispersion that acts on spilled oil to change its physical properties and composition.

References

American Petroleum Institute (API) Publication 4740, 2015. *In-Situ Burning: A Decision-makers Guide to In-situ Burning*.

API Publication 4735, 2005. *In-Situ Burning: The Fate of Burned Oil*.

API Publication 4684, 1999. *Compilation and Review of Data on the Environmental Effects of In Situ Burning of Inland and Upland Oil Spills*.

API Technical Report 1253, 2015. *Selection and Training Guidelines for In-Situ Burn Personnel*.

API Technical Report 1254, 2015. *In-Situ Burn Guidance for Safety Officers and Safety and Health Professionals.*

Barnea, N., 1999. *Health and Safety Aspects of In-Situ Burning of Oil, United States*, National Oceanic and Atmospheric Administration.

Buist, I., 2003. *Oil Spill Response Offshore, In-Situ Burn Operations Manual*, U.S. Coast Guard, Ft. Belvoir: Defense Technical Information Center.

ExxonMobil. 2008. *Oil Spill Response Field Manual*. ExxonMobil Research and Engineering Company, Fairfax, VA.

Fingas, M.F., 1998. *In Situ Burning of Oil Spills: A Historical Perspective*, National Institute of Standards and Testing (NIST) Special Publication 935, In Situ Burning of Oil Spills Workshop Proceedings.

International Maritime Organization (IMO), 2014 (Draft). *Guideline for Oil Spill Response Offshore In-Situ Burning,* International Maritime Organization, London, UK.

Mabile, N., 2012. *Controlled in-situ burning: transition from alternative technology to conventional spill response option.* Proc. of the 33rd Arctic and Marine Oilspill Program Technical Seminar, Appendix A. Environment Canada, Ottawa, Canada.

Mabile, N. 2013. *Considerations for the Application of Controlled In-Situ Burning*, Society of Petroleum Engineers, Oil and Gas Facilities, 2(2):72–84.

McCourt, J., I. Buist, and S. Buffington, 2000. *Results of Laboratory Tests on the Potential for Using In Situ Burning on Seventeen Crude Oils*, Proceedings of the 23rd Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa. pp. 917–922.

U.S. National Response Team (NRT), 1998. *Bibliography on In-Situ Burning*, National Response Team—Science and Technology Committee, Revised, Washington, DC.

U.S. Coast Guard (USCG), 2003. *Oil Spill Response Offshore, In-Situ Burn Operations Manual*, U.S. Coast Guard Report No. CG-D-06-03. Research and Development Center. Groton, CT.

AMERICAN PETROLEUM INSTITUTE

1220 L Street, NW
Washington, DC 20005-4070
USA

202-682-8000

Additional copies are available online at www.api.org/pubs

Phone Orders:	1-800-854-7179	(Toll-free in the U.S. and Canada)
	303-397-7956	(Local and International)
Fax Orders:	303-397-2740	

Information about API publications, programs and services is available on the web at www.api.org.