FATE OF BURNED OIL
IN-SITU BURNING

Things You Should Know

The highest priority for oil spill response is ensuring the health and safety of the public and the response personnel from effects of spilled oil and the potential consequences from cleanup.

The primary potential pathway for human exposure to burned oil through ISB is inhalation of small diameter particulates. To date, measurements during burns have found elevated particulate levels for only short distances downwind of a burn.

Burn residue from incompletely combusted oil has much less acute toxicity compared to the original oil as the lighter, more toxic components are destroyed by burning.

Measurements of heat transfer from on-water burns to the underlying water column concluded some heat transfer occurs, but the effect on water temperature is minor.

Birds and animals will generally avoid fire if able to flee. Removing the oil through ISB reduces the chance of exposure to both wildlife and humans.

The potential health concerns associated with ISB have either no effect, or can be reduced or eliminated

Overview

In-situ burning (ISB) is a response technique that removes spilled oil from a land, snow, ice, or water surface by igniting and burning the oil. ASTM International (2014) defines controlled in-situ burning as "burning when the combustion can be started and stopped by human intervention." The combustion by-products (primarily carbon dioxide and water but also particulates, gases, and other minor components) are released to the atmosphere, with the possibility of some unburned oil or incompletely burned oil residue remaining at the conclusion of a burn.

One of the greatest benefits from ISB is that a burn can rapidly reduce the volume of spilled oil and minimize or eliminate the need to collect, store, transport, and dispose of recovered oil and oily wastes. Decision-makers from federal, state and local agencies or other stakeholders must consider the benefits and risks of conducting a burn versus using other response options, since all options have potential environmental and human health risks. ISB also has the potential to significantly reduce the duration of cleanup operations. In certain instances, ISB might provide the only means of quickly and safely eliminating large amounts of oil.

One of the greatest priorities for oil spill response is ensuring the health and safety of the public and the response personnel from effects of spilled oil and consequences from cleanup. Combustion of oil in the open environment does not result in the total destruction of the hydrocarbons. The primary combustion by-products from ISB are gases and particulates The remaining residue and unburned oil contain elevated concentrations of heavier compounds due to decreased total material. The potential health concerns associated with ISB have either no effect, or can be reduced or eliminated.

This fact sheet summarizes in greater depth the human health and environmental effects of ISB.

Fact Sheet Series

Introduction

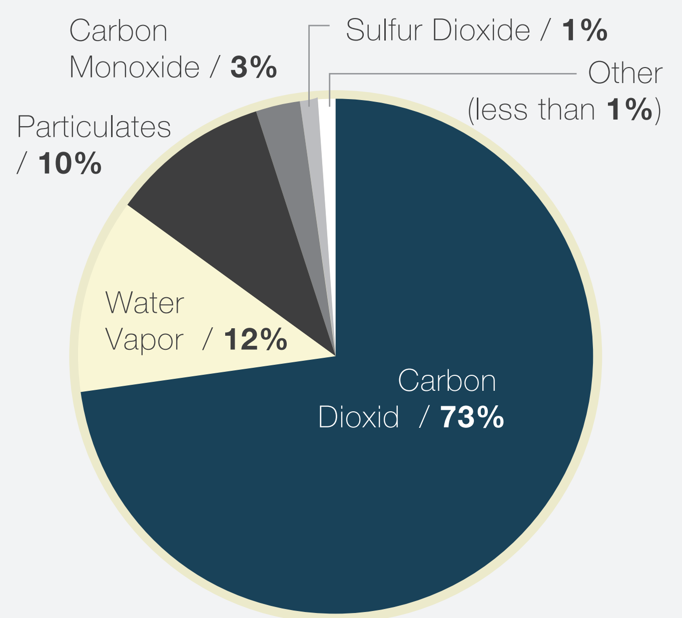
The primary goal of ISB is to minimize the environmental impacts of the oil by rapidly reducing the quantity of the oil through burning. Since burning oil may generate large amounts of black smoke, there are concerns about the effects of the smoke plume on humans, wildlife and the environment. In addition, after ISB, a small percentage of unburned oil may remain from the spill and residual by-products may be released into the environment. These residues and combustion by-products have the potential to negatively affect human health and the environment. **ISB Fact Sheet 2 – Fate of Burned Oil** provides greater detail about the physical and chemical fate of burned oil in the environment.

Combustion By-Products and Residues from ISB

Combustion of oil in the open environment does not result in the total destruction of the hydrocarbons. Although most oil is converted to carbon dioxide and water vapor, inadequate natural mixing of oxygen from air into hydrocarbon vapors yields incomplete combustion.

The primary combustion by-products from ISB are gases and particulates. **Figure 1** shows a typical distribution of by-products from crude oil burns, with the most abundant being carbon dioxide and water vapor.

FIGURE 1. Typical Combustion by-products from burning crude oil. (modified from Ross 1996)



Since no burn is 100 percent efficient, residue and unburned oil remain after a burn, as a fraction of the original amount of oil. The remaining residue and unburned oil contain elevated concentrations of heavier compounds, including polycyclic aromatic hydrocarbons (PAHs), due to the substantially smaller oil volume but are generally depleted of the more volatile components (Buist, 2013). Depending on the spill circumstances, the description of a burn residue can range from thick, sticky liquids to semi-solid tar-like or brittle substances. For more information on PAHs, please refer to **ISB Fact Sheet 2 – Fate of Burned Oil** Another possible combustion ISB by-product is dioxin, which is a persistent chemical in the environment. However, measurements during test burns and the Deepwater Horizon incident found only background levels, which indicate that dioxins are not produced by burning oil (Fingas, 2012).

What are the Human Health Effects from Oil Spills and ISB

One of the greatest priorities for oil spill response is ensuring the health and safety of the public and the response personnel from effects of spilled oil and consequences from cleanup. The primary pathways for human exposure to spilled and burned oil are:

- **Inhalation** — breathing particulates, unburned volatile organic compounds (VOCs) and combustion by-products for ISB and primarly VOCs for the spilled oil.
- **Skin Absorption** — physical contact with spilled oil and burn residues.
- **Ingestion** — while rare, incidentally consuming spilled crude oil, heavier petroleum products and burn residue.

Crude oils and petroleum products are mixtures of thousands of different chemicals that have different potentials for adverse effects depending on the composition, concentration and exposure. For example, light oils have higher concentrations of VOCs that rapidly evaporate after the oil is spilled which increases the exposure potential in the short term but reduces it over time. Heavier oils generally contain less of these light-weight compounds and their relative effects are mostly from direct dermal contact (skin absorption) with the oil rather than inhalation.

According to the Centers for Disease Control and Prevention (2010), individuals can experience certain symptoms after short-term exposure to petroleum oils, depending on the oil type.

These symptoms include:

- **Inhalation** - irritation to eyes, nose, and/or throat; breathing difficulties; and increased dizziness, disorientation, or headache.
- **Skin Absorption** - skin reddening, swelling, rash, and burning, this may worsen if the skin is also exposed to the sun.
- **Ingestion** - upset stomach, vomiting, and diarrhea, possibly from direct ingestion, or through the consumption of seafood contaminated by oil (a secondary exposure route).

ISB emissions are short lived and not likely to cause significant human health issues. Concentrations of gases and particulates in a smoke plume are highest near the source at ground level. Smoke plumes rise and expand rapidly, so concentrations dissipate with distance from the source.

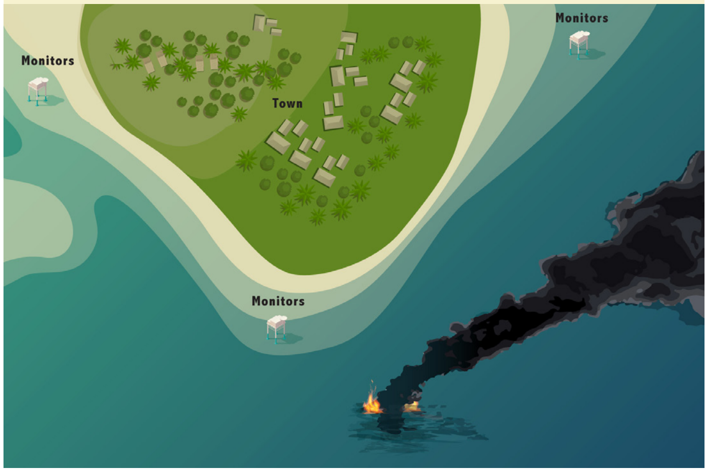
Safety measures and air quality monitoring are generally required as a condition of regulatory approval for ISB to ensure the protection of public health and the on-going safety of its use. In the U.S., the Special Monitoring of Applied Response Technologies (SMART) describes protocols for an offshore burn. These protocols include monitoring and evaluating response effectiveness as well as establishing a rapid collection and reporting of real-time data to the decision-makers. Figure 2 shows how particulate monitors could be placed downwind if a community had the potential for exposure to a smoke plume. Precise monitoring locations are flexible and are determined on a case-by-case basis.

Particulates

One of the primary concerns in the decision to burn spilled oil is the production of smoke plumes and the associated particulates (soot). Particulates are carried aloft in the plumes and can travel long distances downwind before the plume dissipates. Particulates are comprised primarily of elemental carbon, which gives the smoke plume a dark color. The dark smoke in the burn plume can be of aesthetic concern to some and a health concern to nearby human populations or ecologically sensitive areas and resources.

For ISB, the exposure pathway of greatest concern is inhalation of particulates. Particulates are often grouped into two categories: PM10 and PM2.5. PM10 is a coarser mixture of solid and liquid droplets (0 to 10 microns in diameter), and PM2.5 is a finer mixture of particles less than 2.5 microns. Particles smaller than 10 microns are easily inhaled and penetrate deeply into the lungs where they can lodge and

FIGURE 2. Possible location of air quality monitors if an ISB smoke plume passes over a community. (Source: NOAA 2006).



cause damage. It is generally long-term exposure over months to years to PM10 and PM2.5 that affects health. However, short-term exposure to high concentrations can aggravate symptoms in sensitive individuals with existing heart or lung ailments (API, 2004). To date, air quality measurements during ISB operations and oil well and other petroleum fires have not found elevated particulate levels very far downwind.

Weather conditions and fire intensity can determine where and how much particulate will fall to the surface. Larger particulates precipitate quickly near the fire making adjacent locations more likely to be exposed to soot. Smaller particles remain suspended in the air and get carried over long distances by prevailing winds (Barnea, 1995). Studies confirm that under appropriate conditions the effects on air quality at the surface are negligible as particulates widely disperse with distance (Ross et al, 1996). In any case, standard particulate/ air quality monitoring techniques can be used to assess distribution of, and exposure to particulates from, ISB.

Other Gas Combustion By-Products

In addition to carbon dioxide, water vapors and particulates, ISB emits gases at low concentration levels. These gases include carbon monoxide, sulfur and nitrogen oxides, and unburned volatile organic compounds (VOCs) such as benzene, toluene, ethylbenzene, and xylene.

During ISB, low level exposure of VOCs and oil combustion gases may cause temporary irritation of the eyes, nose, throat, and skin, but this exposure is not expected to cause long-term health effects (USEPA, 2010). In general, health effects relate to the specific combustion compound and the concentration of the compound as well as the exposure pathway.

At high concentrations, VOCs and oil combustion gases can contribute to health effects; however, they rapidly disperse downwind and it is highly unlikely personnel will be stationed immediately adjacent to an ISB operation.

ISB Burn Residue and Unburned Oil Human Health Effects

The remaining residue and unburned oil from ISB consist primarily of heavier hydrocarbon compounds that, with the possible exception of PAHs, are less toxic as they are generally depleted of the more volatile/toxic components. Burn residue can range from thick, sticky liquids to semi-solid tar-like or brittle substances.

The health effects from burn residues are generally from physical contact, for example, using rakes, buckets and shovels for manual recovery. As with most oils, prolong contact with residues and unburned oil could cause reddening, swelling and burning of the skin; however, personnel are required to wear appropriate personal protective equipment to mitigate those potential health effects.

Polycyclic Aromatic Hydrocarbons

During ISB, Polycyclic Aromatic Hydrocarbons (PAHs) found in the original oil can be completely or partially destroyed or converted into higher molecular (larger) PAHs. The larger PAHs are considered less acutely toxic and low concentrations of the larger PAHs are often found in both soot and residue (NRT, 1992). In air emissions, the concentration of PAHs is low or barely detectable (Barnea, 1995). Overall, because more PAHs are destroyed by ISB than are created, the quantity of PAHs in the smoke plume is less than in the original oil (ASTM, 2014).

Total PAH concentrations in most oils are low and, when spilled, do not pose an acute health and safety exposure concern. The PAHs concentrations remaining in the unburned oil or burn residue will generally be higher than the spilled oil due to the substantially reduced volume but personal protective equipment and other mitigation measures mentioned above are typically sufficient to eliminate these PAH related human health concerns.

What are the Environmental Effects from Oil Spills and ISB

ISB Wildlife Environmental Effects

Similar to the effects on humans, aquatic and terrestrial wildlife can be exposed to the spilled oil as well as ISB emissions and the burn residue and unburned oil – which often resembles a thick tar-like substance – through inhalation, physical contact and ingestion.

On Water

Inhalation of ISB air emissions by wildlife is possible, particularly near the site of the oil spill. Birds, turtles and air-breathing mammals in close proximity to the burn can be exposed to these particulates and gases. Birds may also inhale particulates and combustion gases if they fly through the ISB smoke plume. These wildlife can also be exposed to the more toxic VOCs of the spilled oil if ISB is not utilized. This exposure is generally only a concern for a relatively short time in the vicinity of the spill because the floating oil quickly loses its VOCs and concentrations quickly dissipate with distance from the source. Exposure of wildlife to during ISB is a concern, and trained wildlife observers should be used during ISB to ensure that wildlife are not in the general vicinity of a burn. Sometimes wildlife can be in the vicinity if sargassum or other food sources are entrained in the oil to be burned. Having trained observers to verify no wildlife are present and to remove wildlife in the event they are present helps mitigate the potential for physical exposures to burning oil.

Effects from physical contact are similar for both the spilled oil and burn residue or unburned oil as they can foul the gills, feathers, or fur of wildlife. The residue and unburned oil from ISB has much less acute toxicity compared to the original oil as the lighter, more toxic components are no longer present. Another concern is that the residue may sink and pose a physical smothering hazard for benthic animals. These risks are, however, low since the quantity of residue is only a very small portion of the original quantity of spilled oil and the area affected by the sinking residue is very localized.

Ingestion of floating residue is possible by fish, birds and mammals. Although both floating and sinking residue could pose some risk of toxicity due to consumption, results from burn studies indicate that burn residues have little or no aquatic toxicity (Blenkinsopp et al. 1997).

On Land

During inland ISB operations, the presence of wildlife is a concern although birds and animals will generally avoid fire if able to flee. Responders are typically required to take measures to prevent risk of injury to any wildlife, especially endangered or threatened species. Natural resource specialists may be consulted to determine if sensitive wildlife or habitat resources are at risk from the burn and may suggest additional protection measures. Examples of protection measures include temporary hazing techniques and physical removal of individual endangered or protected animals (under the authority of appropriate trustee agencies) (USEPA, 1995).

The biggest effect on wildlife is the effect of the burn on habitats, resulting in a possible loss of food and shelter (Barkley, 2006). Invertebrate and insect populations tend to decrease in the area of the fire because eggs, food, and shelter are destroyed (Barkley, 2006). RRT guidelines state that burn residues will be collected immediately following an in-situ burn to minimize exposure to wildlife and habitat. Any impacts resulting from ISB would be less than those from a large, uncontained oil spill (USEPA, 1995).

ISB Habitat Environmental Effects

On Water

When oil is burned on water, most of the heat generated radiates upward. Measurements of heat transfer to the water below in tests conclude that some heat transfer does occur; however, the effect on water temperature is minor because only a narrow layer of water immediately beneath the fire is heated. Burns that occur on ice have shown less than expected melted ice because the heat radiates upward rather than back to the ice surface. The burn residue left on the ice after ISB does have the potential to absorb more sunlight and create localized melting if the burn residue is sufficiently concentrated in an area.

Studies show that water below the burning oil has slightly elevated concentrations of hydrocarbons after a burn but that this slight elevation causes little or no increase in the toxicity of the water. As a result, the use of ISB is not expected to have a significant effect on water column oil concentrations, and water column plants are not at risk from ISB (Fingas and Punt, 2000).

On Land

Oil spilled on land can penetrate some soils. The extent of penetration depends on porosity/permeability of a soil, its saturation level, depth to the water table, and viscosity of the oil. Light oils are more able to penetrate into soils than medium or heavier oils. Oils cannot easily penetrate into clay or other low permeability soils. Oil heated during ISB will become less viscous and could penetrate more deeply into a soil that is not saturated before it is burned resulting in greater and longer term impacts to the soil habitat.

ISB also affects the general habitat at the burn site but in the same manner as other fires. Many plants are accustomed to fire as wetlands and prairies routinely burn from natural phenomena and man-made prescribed burns. For plants, protecting the roots from high temperatures is critical so that the plant may recover from the effects of the burn. Research has shown that water-saturated soil or those with standing water, snow, or ice is enough to insulate plant roots from heat of a burn, as shown in Figure 3 and Figure 4.

Plants can also be damaged from the oil itself before an ISB is initiated. For example, a wetland plant could be heavily coated with oil and suffocate. In general, the oiling of wetland and terrestrial habitats will significantly impact all of the resident flora and fauna as well as the birds, fish and other wildlife that may venture into the affected habitat. Removing the oil by burning can have short term habitat impacts but reduces the long term exposure to all life forms.

FIGURE 3. ISB conducted in a freshwater marsh in snow. (NOAA 1993)

Figure 4 shows a marsh in Utah immediately after an ISB on spilled diesel, and Figure 5 shows recovery in the same area 1.5 years later. The burn was not initiated until almost seven weeks after the spill, and standing water prevented diesel penetration to plant roots and limited any toxic effects. The water also protected the plant roots from the heat from the fire which allowed for a nearly complete recovery. In contrast, cleanup workers and equipment would have pushed oil into marsh soils and sediments, which could have led to toxic effects (Michel et al. 2002).

SIMA and Trade-off Decision-making for ISB

Careful consideration is given before applying ISB to an oil spill on water or land and many factors are analyzed prior to approval, including geographic area, anticipated weather conditions, safety, wildlife effects, human health effects and socio-economic concerns. These considerations are best made in the pre-spill planning process when ample time is available to make decisions. A Spill Impact Mitigation Assessment (SIMA)[1] consensus-based planning tool can be used to objectively evaluate various response options, including ISB, to determine which option or set of options will result in the least overall impacts. The SIMA process brings together key stakeholders, including regulators and natural resource trustees, to address resource-management decision-making needs for an oil spill response. The stakeholders and response decision makers compare and rank the pros and cons (or "trade-offs") of the applicable response options relative to the spilled oil's potential impact on the ecological, socio-economic and cultural resources at risk and choose those that will best mitigate the potential impacts.

During a response, when the oil is spreading and weathering, time is often of the essence, so a pre-determined decision-making process can help. Some US regional response teams have developed guidelines to help responders evaluate possible response options. For more information on SIMA and ISB trade-offs, please refer to **ISB Fact Sheet 4 – Assessing ISB Benefits and Risks.**

FIGURE 5. The same Utah marsh 1.5 years after the burn showing close to full recovery. (Michel et al. 2002)

Figure Sources

Figure 1 – Ross, J.L., Ferek, R.J & Hobbs, P.V. (1996) Particle and Gas Emissions from an In Situ Burn of Crude Oil on the Ocean, Journal of the Air & Waste Management Association, 46:3, 251-259, DOI: 10.1080/10473289.1996.10467459.

Figure 2 – NOAA. 2006.Air quality monitoring figure. Retrieved from http://response.restoration.noaa.gov/sites/default/files/SMART_protocol.pdf

Figure 3 – NOAA. 1993. ISB conducted in a freshwater marsh in snow. Retrieved from previous API report: http://www.oilspillprevention.org/~/media/Oil-Spill-Prevention/spillprevention/r-and-d/in-situ-burning/api-technical-report-1256-in-situ-burnin.pdf

Figure 4 – Michel, J., & Miles, S. (2002). Recovery of four oiled wetlands subjected to in situ burning. API publication #4724. Washington, DC: American Petroleum Institute.

Figure 5 – Michel, J., & Miles, S. (2002). Recovery of four oiled wetlands subjected to in situ burning. API publication #4724. Washington, DC: American Petroleum Institute.

Figure 5 – S. Lehmann, NOAA.

[1] The term Net Environmental Benefit Analysis and its acronym NEBA have been used extensively over the years to describe a process used by the oil spill response community for guiding selection of the most appropriate response option(s) to minimize the net impacts of spills on people, the environment and other shared values. Industry has consulted directly with non-industry stakeholders who have expressed support for transitioning to a more appropriate term. Industry is thus introducing the term Spill Impact Mitigation Assessment (SIMA) as a replacement for NEBA. For purposes of this document, all references to SIMA should be understood to mean NEBA in its broader context.

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