

RISK COMMUNICATION FOR *IN-SITU* BURNING

THE FATE OF BURNED OIL

REGULATORY AND SCIENTIFIC AFFAIRS DEPARTMENT
API PUBLICATION 4735
APRIL 2004



American
Petroleum
Institute



Documents

Document Sharing Hub

RISK COMMUNICATION FOR *IN-SITU* BURNING

THE FATE OF BURNED OIL

Regulatory and Scientific Affairs Department

API PUBLICATION 4735

PREPARED UNDER CONTRACT BY:

D. SCHOLZ, S.R. WARREN JR., AND A.H. WALKER,
SCIENTIFIC AND ENVIRONMENTAL ASSOCIATES, INC.
CAPE CHARLES, VIRGINIA

AND

J. MICHEL
RESEARCH PLANNING, INC.
COLUMBIA, SOUTH CAROLINA

FOREWORD

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.

All rights reserved. No part of this work may be reproduced, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, N.W., Washington, D.C. 20005.

Copyright © 2004 American Petroleum Institute

This Page Intentionally Left Blank

Table of Contents

	Page
Foreword	iii
Table of Contents	v
List of Figures	vii
List of Tables	vii
Overview	ix
I. Introduction	1
Purpose of This Booklet.....	1
II. Oil Chemistry Review	3
What is Oil?	3
How Does Burning Change the Oil?	5
III. Burn Residue on Water	6
How Burn Residue Behaves On Water.....	6
Likely Fate of Residues That Are Not Recovered	8
Environmental Concerns of Burn Residues from On Water ISB	8
Direct Contact (coating).....	9
Ingestion.....	9
Stranding/Smothering	9
Relative Toxicity of Soluble Components of Burn Residues	10
IV. Burn Residue on Land	11
How Burn Residues Behaves on Land.....	11
Likely Outcome of Residues That Are Not Recovered On Land	13
Relative Toxicity of Burn Residues On Land	13
Environmental Concerns of Burn Residues from On Land ISB.....	14
V. ISB Case Histories and Lessons Learned	15
Case Study No. 1 – Trans-Alaska Pipeline, Alaska, February 1978.....	15
Case Study No. 2 – Marathon Pipeline, Illinois, January 1995	15
Case Study No. 3 – Mosquito Bay, Louisiana, April 2001	16
Case Study No. 4 – Ruffy Brook, Minnesota, April 2001	17
Case Study No. 5 – Prince William Sound, Alaska, March 1989.....	18
Case Study No. 6 – NOBE, Newfoundland, Canada, August 1993.....	19
VI. Air Quality Issues – Fate of Burn Residue in the Air.....	20
Understanding the Problem.....	20

Table of Contents, continued

	Page
Outcome of Airborne Burn Residue	21
Exposure to Airborne Residue	22
Particulate Matter	22
Gases	22
ISB & Health and Safety Issues	24
Response Personnel	26
General Public	27
Air Monitoring for an <i>In-situ</i> Burn	27
SMART and Monitoring	28
VII. Burn Residue Issues Summarized	30
VIII. Other ISB Information	32
List Of Acronyms	32
References Cited and Further Reading	34
List of Contacts for Additional Information	38
Acknowledgements	39

List of Figures

	Page
Figure 1. Mosquito Bay – one hour after first burn ended	16
Figure 2. No burn residue on surface; free unburned oil in burrows	16
Figure 3A/3B Mosquito Bay – (A) Heavily oiled vegetation; (B) Same area hours after burn	16
Figure 4. Oblique aerial photograph of the Ruffy Brook spill site.....	17
Figure 5. The ponded wetland contaminated with medium crude oil discharged from the 34-inch pipeline at the Ruffy Brook spill site	17
Figure 6. Photograph of the nature of the tarry residue that was manually removed within three days after the burn	17
Figure 7. Exxon Valdez test burn	18
Figure 8. NOBE experimental burn	19
Figure 9A/9B NOBE Burn - (A) Residue recovery; (B) Residue examination.....	19
Figure 10. Typical composition of crude oil and combustion products produced from an <i>in-situ</i> burn	20
Figure 11. Typical smoke plume dispersion	21
Figure 12. Possible smoke plume dispersion with inversion	21

List of Tables

	Page
Table 1. Behavior of Burn Residue for Different Types of Oil for On Land Burns.....	12
Table 2. Air Quality Standards	25
Table 3. Potential Health Effects from ISB Smoke Plume Exposure.....	25

This Page Intentionally Left Blank

Overview

- The American Petroleum Institute (API) commissioned the preparation of two booklets to help bridge the gap in the understanding of *in-situ* burning use, effectiveness, and effects.
- This booklet (first of two) focuses on *in-situ* burning effects, risks, and the fate of oil once it has been burned.
- This series was developed as a training tool or planning tool for *in-situ* burning. It is not exhaustive, and is **NOT** an operations manual. Each spill is unique and decision makers must use their judgment to meet legal and environmental requirements.
- Crude oil is a complex mixture of thousands of different compounds, composed primarily of carbon, hydrogen, sulfur, nitrogen, and oxygen. Hydrocarbons (composed solely of carbon and hydrogen atoms in various combinations) are the most abundant compounds found in crude oils.
- *In-situ* burning (ISB) is considered as effective as mechanical recovery options on open water when the oil is contained; under these circumstances both methods can result in 80 to 90 percent removal. However, for spills on water, only 20 percent of the total discharge is typically contained and thus available for recovery or burning.
- Burning can be effective, but needs to be conducted as quickly as possible if weather conditions are favorable (before the oil has emulsified or spread so far that collection of significant quantities is too difficult).
- ISB aims to remove at least 90% of the discharged oil (that has been contained for burning) from the environment, whether on land or on water. The overriding goal is to accomplish this removal while minimizing adverse environmental effects and ensuring that any resultant air pollution does not jeopardize human health.
- ISB may be useful during a continuous release situation from an offshore production platform when the necessary burn equipment can be brought on scene.
- *In-situ* burning can be a very effective tool on shore and in marsh areas, where the oil is contained by the environment and other response options are limited by topography.
- ISB has always been considered as a primary Arctic spill response countermeasure. High ice concentrations contain oil for burning while rendering offshore mechanical recovery difficult or ineffective. ISB is the countermeasure of choice for removal of oil pools on ice and may also be effective for oiled snow.
- On water, most burns produce small amounts of taffy-like or brittle oil residues that can be recovered manually, although, in some cases, the burn residues from crude oil and heavy refined oils may sink after cooling.
- In open water, unrecovered residue may float to nearby shorelines where it can be manually removed. Recovery of sunken residue is very difficult and thus not likely to be undertaken.
- Burn residue tends to be sticky and, on land, may adhere to vegetation and sediments. Removing thick residues may be required.

- Burn residues can be chemically characterized as weathered oil, with most of the light fractions burned off. Thus, further changes in composition will be slow.
- On open water, burn residue from an effective burn presents a minimal environmental risk because of the small amount of residue (1-10 %) present relative to the initial volume burned. During an incomplete burn, the volume of remaining oil and partially burned oil may be a greater percentage and more difficult to remove using standard removal techniques.
- Exposure to burn residue may affect biologically sensitive resources. On open water, effects may occur if the residue is ingested (by birds or sea turtles). The residue may also physically coat and smother animals and habitats. Chemical and physical impacts to biologically sensitive resources on land are essentially the same, but include potential impacts to soils and vegetation from both the burn and burn residue. The chemical toxicity effects of burn residue are generally less than the effects from the original oil.
- *In-situ* burning may be used to quickly remove oil from the environment thereby eliminating the need for further handling and storage of oil and minimizing further impacts.
- Burning oil (on land and on water) produces plumes of airborne emissions composed of a wide variety of gases as well as particulate matter (soot). The most abundant components within the smoke plume are CO₂, water vapor, CO, SO₂ and unburned carbon particles.
- Air pollution from a burn is usually short-lived, and, depending on wind speed, the smoke plume is often dispersed within 10-20 miles (16-32 km) from the burn site. Additionally, the environmental impacts from ISB are often far less than if the oil were allowed to weather, spread, or remain in the environment.
- One major concern with *in-situ* burning, and the decision to burn or not to burn, is the potential for human health effects of inhaled smoke particles, carbon monoxide, sulfur dioxide, PAHs, VOCs, and metals. The effects will depend on the amount of burn products inhaled and the length of exposure, both of which are related to proximity to the burn, the volume of oil burned, burn efficiency, burn duration, wind direction and speed, and atmospheric stability, as well as a person's age and overall health, prior to exposure.
- Individuals most likely to be affected by the burn by-products are those people who are sensitive individuals, such as children or those with heart or lung disease.
- Worker health and safety is also of primary importance during a burn and individuals associated with the response must have up-to-date 40-hour Occupational Safety and Health Administration (OSHA) hazardous materials training as well as other more specialized training. The concerns can include:
 - Fire control - preventing unwanted ignition or secondary fires
 - Ignition control – using specialized equipment and trained personnel requires additional safety precautions
 - Vessel Safety – at sea, a burn requires several vessels to work together often under difficult circumstances. Boom handling for corralling the spilled oil should also be conducted by experienced, trained personnel

- Personnel exposures – response personnel may be in danger from the fire or flames, exposure to high concentrations of particulate matter, or other health and safety issues such as working in extreme heat or cold conditions,
- Modeling the *in-situ* burn plume can provide critical information to help responders determine potential for general public impacts from exposure to the burn smoke. Models available to estimate the dispersion of *in-situ* burn products include, for example:
 - National Institute of Standards and Technology’s (NIST) ALOFT (A Large Outdoor Fire plume Trajectory) model
 - US EPA’s ISCST3 (Industrial Source Complex, Short Term) model
 - US EPA’s CTDMPPLUS (Complex Terrain Dispersion Model PLus algorithms for Unstable Situations)
 - Offshore and Coastal Dispersion (OCD) model
 - Earth Tech, Inc’s. CALPUFF model, adopted by U.S. EPA
- The Special Monitoring of Applied Response Technologies (SMART) protocol establishes a monitoring system for rapidly collecting and reporting real-time information on *in-situ* burning or dispersant operations.
 - This monitoring information system is designed for use during either land or water spill response operations, using a minimum of three separate teams for the monitoring task.
 - Prompt notification needs to be given to the Monitoring team when *in-situ* burning is being considered to give them enough time to activate and arrive on scene.
- *In-situ* burning has been widely used on land spills with numerous examples of success. There is limited experience from a few on-water efforts, but controlled testing has confirmed it can be a viable option.
- *In-situ* burning can provide net environmental benefit (e.g., tradeoffs are worth it). Removal of bulk oil by ISB can enhance the recovery rate of impacted areas, and lessen the overall environmental effects of an oil spill. Issues surrounding effects of residual oil or exposures to smoke plumes are far more manageable and environmentally less hazardous than the long-term impacts of persistent oil slicks or heavily oiled shorelines.

This Page Intentionally Left Blank

Section I—Introduction

You are in the midst of a large oil spill and it's your first month on the job. Approximately 20,000 gallons (476 bbl/65 tons) of a medium weight crude oil has been discharged into the environment and the responders are looking for options to remove this oil that will also minimize the potential impacts to the environment. One of the possible strategies is to burn the oil in place (i.e., *in-situ* burn - ISB). You want to verify the appropriateness of this removal method for today's specific spill conditions, identify and present any pros and cons, additional operational requirements, worker health and safety issues, public health issues, monitoring requirements, etc.

Needless to say, time is of the essence. You have had basic oil spill response training, and you have heard of ISB, but have never been involved in an ISB-related response. During your training, you remember that there were several guidance documents that have been developed to assist responders in understanding the concept of ISB...

Purpose of This Booklet

This scenario may not be real, but the circumstances are possible. ISB is a response option that has been used far less frequently than mechanical countermeasures (booms, skimmers, etc.) and consequently, familiarity with ISB operations is limited. There are ISB "experts" in the US and international responder tools, but the intentional practice of this response tool remains relatively limited for both water and land situations. As our network of experienced oil spill responders retire, their knowledge and hands-on experiences with the various response tools like ISB may be lost. This document was designed to capture that knowledge and present it clearly and concisely so you will have the necessary information to understand issues associated with fate and effects of oil to which ISB has been applied. It is not a set of instructions for carrying out a specific ISB.

During the 1998 *In-situ* Burning of Oil Spills Workshop (Walton and Jason, 1999), participants worked to determine the state of knowledge and the research needs of the user community regarding ISB. The participants believed that the "...lack of adequate knowledge by public and other decision-makers was a major impediment to acceptability and utilization of *in-situ* burning" (Walton and Jason, 1999). They determined that the knowledge-base for burn residue and air impacts is mostly adequate, but this information needs to be presented such that decision-makers better understand the function of *in-situ* burning and the tradeoffs facing them in using this technique when responding to an oil spill.



An oil slick undergoing an *in-situ* burn.

This booklet is a reference document for oil spill response decision-makers, to **provide an accurate synthesis of available information concerning of the fate and effects of burned oil on water, on land, and in the air.**

This booklet also identifies and explains specific terms associated with oil that may be used by technical experts during planning or response operations. The first time a new technical term is used within this booklet, it will appear in **ALL CAPS** signifying that a more detailed explanation or definition is present in the right or left margin near where the word(s) is first used within the main text.

A second booklet, “A Decision-maker’s Guide to *In-situ* Burning,” discusses the operational issues and concerns associated with an *in-situ* burn on land or on water.

Who Gets to Make the Decision to Conduct an ISB?

In the United States, the use of ISB as an oil spill response tool is regulated by both federal and state laws. Regional Response Teams (RRT), made up of federal and state agencies, have developed guidelines that provide a common decision-making process to evaluate the appropriateness of using ISB during a spill response. The decision to use ISB is not defined by the spill volume or intensity, but is based primarily on the viability of the countermeasure based on the incident-specific conditions.

The **UNIFIED COMMAND (UC) FEDERAL ON-SCENE COORDINATOR (FOSC)** must consider ISB a practical option for the incident-specific conditions. Before initiating an ISB, the Unified Command should conduct a consultation with Regional, State, and Local Air Quality Officials. Because the smoke from an ISB has a much greater ability to migrate than the oil slick itself, careful consideration of potential air quality impacts on neighboring States, regions, and countries is especially important. Finally, the UC then consults with meteorologists, response contractors, and experts on burning to further determine ISB viability for the incident-specific conditions. The UC will seek approval/concurrence of the RRT members prior to initiating the burn (where feasible).

In many states, the decision to conduct an ISB on land does not always require concurrence by the RRT; however, it is strongly recommended that the RRT be notified.

The **Federal On-Scene Coordinator (FOSC)** is the pre-designated, senior government authority during oil and hazardous materials spill. This position’s authority is designated under the National Contingency Plan.

The **Unified Command** is composed of FOSC, State on-scene coordinators, Local agency, and a responsible party (RP) representative.

Section II—Oil Chemistry Review

What is Oil?

Decision-makers need a comprehensive understanding of the oil itself in order to understand the behavior of any ISB by-products and the potential impacts from an *in-situ* burn.

Oil is not one compound nor chemical, but a complex mixture of thousands of different compounds, primarily comprised of carbon, hydrogen, sulfur, nitrogen and oxygen (NRC, 2003) in various combinations within the oil. Once it is exposed to the atmosphere, oil undergoes seven weathering processes: **SPREADING**, **EVAPORATION**, **DISSOLUTION**, **NATURAL DISPERSION**, **EMULSIFICATION**, **PHOTO-OXIDATION**, **SEDIMENTATION**, and **BIODEGRADATION**. The rate and extent of these weathering processes vary by the type of oil, air/water temperatures, wind, and wave conditions (for on-water spills).

Because the composition of crude oil differs, and these are significantly different from refined products, spill responders must have a clear understanding of the type of oil that has been discharged. For instance, one crude oil may have many components that evaporate quickly, whereas another may be composed of many heavy components that can persist in the environment for a long time. A more detailed discussion on oil chemistry can be found in the booklet, “Fate of Spilled Oil in Marine Waters: Where Does It Go? What Does It Do? How Do Dispersants Affect It? An Information Booklet for Decision-Makers” and is available from API Publications at www.api.org.

HYDROCARBONS are the most abundant organic compounds in crude oil (NRC, 2003). There are essentially three groups of hydrocarbon components in every crude oil:

1. Lightweight components (low molecular weight)
 - contain 1 to 10 carbon atoms (C1 to C10);
 - evaporate and dissolve more readily than medium or heavy-weight components, and also leave fewer residual compounds (often called residue) than medium or heavy-weight components;
 - are thought to be more **BIOAVAILABLE** to animals (readily taken up by an organism) than medium or heavyweight components;
 - are potentially flammable and readily inhaled, so they are of concern relative to safety and their potential **TOXICITY** to animals and humans; and

Evaporation is the preferential transfer of light- and medium-weight oil components from the liquid to the vapor phase. During the first 24 to 48 hours of a spill, evaporation is the single most important weathering process from the standpoint of volume reduction. It is often the primary process involved in the natural removal of oil from the water/land surface.

Spreading is the movement of the entire slick horizontally along the surface of the water or land. Spreading dominates the initial stages of a spill and involves the whole oil (the oil is not partitioned chemically at this point).

Dissolution is the transfer of the oil components from a surface slick into solution in the water column. This is a relatively insignificant weathering process and most dissolution takes place within the first 24 hours following the discharge.

Natural Dispersion occurs as the oil slick forms small oil droplets that become incorporated into the water column as a dilute oil-in-water suspension. Natural dispersion reduces the volume of oil on the water surface but does not affect the chemical composition of the oil.

Emulsification is the mixing of water droplets into oil. Emulsification tends to increase the total volume of the oil, often by a factor of two to four. Water-in-oil emulsions are highly viscous and further weathering of the emulsified oil can be significantly reduced.

Photo-oxidation transforms the oil into other by-products during exposure to sunlight. It occurs at the very surface of the oil and plays a relatively minor role in the overall weathering of the oil. This process may continue over a period of several weeks to months.

Sedimentation is the incorporation of oil (on water) into both suspended and bottom sediments.

Biodegradation is the process whereby naturally occurring bacteria and fungi consume hydrocarbons as a food source. Carbon dioxide and water are produced as by-products. This is a significant, but relatively slow, process in oil weathering.

Hydrocarbons are chemical compounds composed solely of carbon and hydrogen.

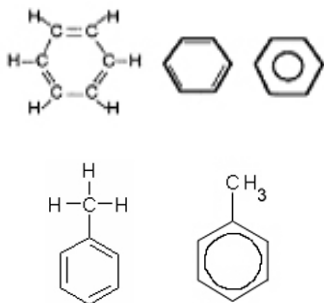
To be **Bioavailable** is to be in a form that is conducive to uptake (e.g., ingestion, inhalation) by organisms.

Bioavailability is the tendency of a substance (in this case, individual oil components) to be taken up by a biological organism (Rand and Petrocelli, 1985).

Toxicity represents the degree of danger a substance poses to animal and plant life. Acute toxicity occurs quickly and often quantified as death. Chronic toxicity occurs over the life of an organism, typically quantified as impacts to reproduction, growth, or behavior.

Mono-aromatics are a class of hydrocarbons characterized by a single ring with six carbon atoms. Mono-aromatics are considered the most acutely toxic components of crude oils, and are also associated with chronic and carcinogenic effects. Many mono-aromatics are also soluble in water.

Benzene and Toluene are petroleum hydrocarbon mono-aromatic components that are characterized by single rings of six carbon atoms.



- must be present in order for the oil to ignite easily
- 2. Medium-weight components (medium molecular weight)
 - contain 11 to 22 carbon atoms (C11 to C22);
 - evaporate or dissolve more slowly than lightweight components, over several days;
 - may leave behind additional residual compounds which can appear as a coating or film;
 - are regarded as more potent toxins than the lightweight components; but
 - are not as bioavailable as lower-weight components, resulting in lower exposure rates for organisms.
- 3. Heavyweight components (high molecular weight)
 - contain 23 or more carbon atoms ($\geq C23$);
 - undergo little to no evaporation or dissolution;
 - can cause long-term ecological/biological effects via smothering or coating by residual compounds; residuals may remain in the water column and sediments indefinitely (Helton, 1996); and
 - are not very bioavailable, resulting in much lower exposure rates for organisms when compared to light or medium components.

The effects of spilled oil depend on the chemical composition of the oil itself. Some components that are considered harmful (i.e., **MONO-AROMATICS** such as **BENZENE** and **TOLUENE** in the C1 to C10 range) have a high volatility and are readily taken up through the skin or through inhalation; but, unless the concentration of oil is very high, they will usually evaporate before becoming widely available to organisms in the water column. The air surrounding the spill may contain harmful concentrations of the volatile materials if wind is still. Other oil components may also be considered harmful, but their molecules are very large, making them less soluble in water. Because these components are less soluble, they are also less biologically available to organisms in the water column. The two classes of oil components thought to be the most bioavailable, thus most hazardous for water column organisms, include many of the lightweight components in the C1 to C10 range and the two and three-ring **POLYCYCLIC AROMATIC HYDROCARBONS** (PAHs). (NRC, 2003; Neff and Sauer, 1995) Potentially hazardous levels of bioavailable oil components such as these usually exist in the water column for only a short period of time after a spill.