IN SITU BURNING OF OIL SPILLS

WORKSHOP PROCEEDINGS

NEW ORLEANS, LA
NOVEMBER 2– 4, 1998

William D. Walton and
Nora H. Jason, Editors

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NOTICE

COVER

U.S. Coast Guard and Minerals Management Service sponsored fire-resistant oil spill containment boom performance test using a non-commercial test boom at the Coast Guard Fire and Safety Test Detachment, Mobile, AL, August 1997. William D. Walton, Photographer.

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New Orleans, LA
November 2-4, 1998

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5:00 PM	Panel Chairs Summarize Priorities

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IN SITU BURNING OF OIL SPILLS WORKSHOP
New Orleans, Louisiana
November 2-4, 1998

INTRODUCTION

The Minerals Management Service (MMS), U.S. Department of Interior, is designated as the lead agency for *in situ* burn research in the Oil Pollution Research and Technology Plan prepared under the authority of Title VII of the Oil Pollution Act of 1990 (OPA-90). In response to MMS's continuing effort to ensure the relevance of their research program to the needs of the user community, a workshop on *in situ* burning of oil spills was hosted by MMS in 1994 to present the state of the knowledge and identify research needs.[1] Since that time, significant advances in the acceptance and application of *in situ* burning as an oil spill mitigation method have been made, in part as a result of the MMS-funded research program. As a result of widespread preapproval of *in situ* burning and advances in the technology, MMS hosted this follow-on workshop to update the state of knowledge and the research needs of the user community.

The goals of the *In Situ* Burning of Oil Spills Workshop were:

1. To present the state of knowledge to decision makers from local, state and federal agencies, responders, environmentalists, academia, industry and the user community.

2. To prioritize research and information needs to support decisions on the use of *in situ* burning of oil spills.

The introductory speaker presented a historical perspective covering the more than forty years since the first documented use of *in situ* burning. It was noted that until about 1990, most of the research consisted of observations. After that time scientific principles were seriously applied to the analysis of *in situ* burning. A presentation followed that indicated that some form of preapprovals for *in situ* burning was in place for almost all areas of the United States. The remaining presentations focused on the operational aspects of *in situ* burning including the window of opportunity, fireboom testing, training and preparedness, monitoring and modeling, alternative approaches and inland/fresh water burning. These presentations highlighted the advances in the preparedness for and technology of *in situ* burning made in the past five years.

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[1] Jason, Nora H., ed., *In Situ* Burning Oil Spill, Workshop Proceedings, Nat. Inst. Stds. and Tech., Spec. Pub. 867, 1994 August, 101 p.

The workshop attendees were invited to participate in two breakout discussion panels. One focused on environmental and human health issues and the other on operations issues. The panels reviewed the recommendations from the 1994 workshop and the presentations. From this information and the experiences of the participants, a list of needs and potential methods of implementation was developed. The priorities were determined by a vote of the panel participants. Although the panels focused primarily on their assigned topics, both panels found there was a similar need to improve education, communications and training at wide variety of levels. The recommendations of both panels were combined on this topic.

This Proceedings is the official transmittal of the workshop presentations and recommendations to the sponsor, Minerals Management Service, Department of Interior. It reflects the combined input of the workshop participants and not necessarily the views of the Minerals Management Service. The panel recommendations and the individual papers are presented following this Introduction.

REPORT OF THE ENVIRONMENTAL AND HUMAN HEALTH PANEL

Jean Snider, Ph.D., National Oceanic and Atmospheric Administration
Panel Chair

BACKGROUND

The Environmental and Health Panel believed that much progress had been made since the 1994 *In Situ* Burn Workshop. Several research areas that had been identified at that time have been addressed and require no further work. Uncertainties regarding the toxicity and behavior of the burn residue have been addressed sufficiently to provide evidence that this is not a likely environmental concern. Research has been conducted to explore different techniques for reducing the amount of soot emitted during small scale burns. Although these studies offered promise, scaling them up to a full-scale spill response present an intractable logistical problem. As a consequence, no further efforts on these techniques have been proposed. In other areas, such as smoke plume trajectory modeling, significant progress has been made and that completion of ongoing projects and routine refinements is all that is required.

In other areas, the major work to be done is non-research in nature. Significant effort has been devoted to developing and testing operational procedures for particulate monitoring. Guidelines have been developed for assisting decision makers in defining appropriate conditions for implementing *in situ* burning. Although these tools are available, it is critical that training be conducted frequently on their proper use.

The group believed that lack of adequate knowledge by public and other decision makers was a major impediment to acceptability and utilization of *in situ* burning. Information needs to be presented in such a way to allow people to understand the role of *in situ* burning and the takeoffs facing decision makers in responding to an oil spill. Several efforts at the regional level have been made to encourage the use of *in situ* burning. Both Alaska Clean Seas and the Regional Response Team (RRT) in Region I (New England) have developed educational materials specifically for the response community to use in explaining the role of *in situ* burning. In Louisiana and Alaska efforts have been made to develop systematic procedures to collect data associated with inland burns on actual spills. Both education and better documentation of inland/upland spills were identified as high priority activities: these regional efforts should be built upon to develop a more comprehensive and consistent national approach.

ENVIRONMENTAL AND HUMAN HEALTH PANEL RECOMMENDATIONS

Particulates

Need: Refine the particulate monitoring strategy.

Research: Develop training curricula for monitoring personnel.
Method of implementation: Conduct training and updates at periodic intervals.
Priority: High
Comments: It is critical that decision makers [e.g., on-scene coordinators (OSCs) scientific support coordinators (SSCs)] fully understand the applicability and limitations of the monitoring results. Skills should be exercised through interregional drills, burns of opportunity and refresher training.

Research: Revisit the National Response Team (NRT) particulate guidelines to evaluate the applicability to Regional Response Teams (RRT) and on-scene coordinators (OSC) needs.
Method of implementation: Reconvene panel of experts, including health and spill responders, to assess implementation of National Response Team (NRT) guidelines and identify additional needs.
Priority: High
Comments: Need to change focus of some responders from the apparent application of the document as a standard to the use as guidance or an action level. There needs to be more emphasis on risk assessment during the *in situ* burn decision making process and communicating the decision to the public. An expert panel needs to evaluate these issues and develop recommendations.

Research: Complete studies to characterize performance of instruments used to measure particulates under varying environmental conditions.
Method of implementation: Controlled experiments to examine influence of various factors, such as particulate sources, temperatures, and humidity. Develop appropriate changes in protocols to enhance instrument accuracy.
Priority: High
Comments: Studies are underway at the National Institute of Standards and Technology (NIST) on instrument performance. These studies should be completed and appropriate adjustments made in the field measurement protocols.

Inland/Upland

Need: Develop a better understanding of *in situ* burning takeoffs, pros and cons for different habitats.

> Research: Develop guidelines for proper application of *in situ* burning for different environments.
> Method of implementation: Develop a protocol to collect data on actual spills. This must include not only conditions during burning, but also during long term recovery. Need to revisit and amend existing documentation methods to develop guidelines for different environments (e.g., tundra, marsh, shoreline, swamp, lakes).
> Priority: High
> Comments: Guidelines and documentation are needed on *in situ* burning for marshes, rivers, lakes, tundra, shoreline, and upland (on land). Alaska and Louisiana have begun to develop protocols for documenting *in situ* burns in these environments. These efforts should be shared and adapted for specific environments of concern.

Smoke Plume Trajectory Modeling

Need: Improve smoke plume trajectory modeling capabilities to support *in situ* burn planning.

> Research: Continue to improve existing models.
> Method of implementation: Continue to validate models with real data. Continue to refine with improvements in software. Continue to refine complex terrain capabilities.
> Priority: Medium
> Comments: Some states indicate it is important to have an Environmental Protection Agency (EPA) validated model. This should be continued to be pursued. It is critical that the modelers receive feedback from user community and the user community be aware of model capabilities and limitations. It is critical that users are adequately trained and such training be frequently reinforced through refresher courses, software updates, etc.

Burn Residue

Need: Not applicable.

> Research: No new research was considered necessary either for toxicity or sinking.
> Method of implementation:
> Priority:
> Comments: Regional Response Teams (RRTs) and on-scene coordinators (OSCs) should be strongly encouraged to recover burn residue where feasible, especially in sensitive environments.

Reduction of Soot Emissions

Need: Not applicable

Research: No new research was proposed.
Method of implementation:
Priority:
Comments: Since the 1994 Workshop, research has been conducted with ferrocene and air injection to reduce soot emissions; however, there are major difficulties in the application for operational use. Conceptually it is a good idea and new ideas to reduce soot emissions should be pursued; however, none appear viable for large scale use at the present time.

Non-particulate Emissions

Need: Follow research in non-particulate emissions from *in situ* burning

Research: Follow up on developments and new information on non-particulate emissions from *in situ* burning, including volatile organic compounds (VOCs), polycyclic aromatic compounds (PAHs), and others.
Method of implementation: Review literature.
Priority:
Comments: As research is published on non-particulate emissions from *in situ* burning the response community should consider this work as it applies to *in situ* burning safety plans and monitoring protocols.

REPORT OF THE BURNING OPERATIONS PANEL

LCDR Roger Laferriere, United States Coast Guard
Panel Chair

BACKGROUND

Participants in the Operations Panel included representatives from citizens' groups, petroleum industries, equipment manufacturers, universities, response consultants, oil spill removal organizations (OSROs), and state and federal agencies. The discussion focused on the operational elements of *in situ* burning: what research and development work is needed to enhance *in situ* burn operations. There also was a discussion on the barriers remaining to the successful implementation of *in situ* burning.

The Operations Panel session was divided into two phases. The first phase involved identifying research and development needs within key operational categories:

- Oil characteristics
- Environmental
- Resources
- Deployment

From discussion on these key categories, operational needs emerged.

The second phase involved reviewing illustrations (courtesy of Alan Allen) of a number of *in situ* burn deployment scenarios for inland, upland (on land), shoreline, coastal and offshore environments. This was intended to ensure that no research and development issues were overlooked. In a few cases, new research needs emerged. But, for the most part, the scenarios reinforced the research and development needs identified in the first phase.

The research in the area of *in situ* burn operations since the 1994 Workshop has strengthened the viability of *in situ* burning as an oil spill response tool. Significant advances have occurred in the *in situ* burning preapproval process, training, operational procedures, and equipment. The primary operational concern of community and worker exposure to combustion products has been addressed.

In situ burning has been used as a proven response technology for several inland and upland spills. *In situ* burning is the only viable alternative in many remote locations, where mechanical, dispersant and the no cleanup options are more damaging to the environment. Although the opportunities for using *in situ* burning offshore have been limited, it remains a viable response option. The Operations panel agreed with the Environmental and Health panel that the lack of adequate knowledge by the public and other decision makers is the primary barrier to *in situ* burning utilization.

BURNING OPERATIONS PANEL RECOMMENDATIONS

Operations

Need: Enhance *In Situ* Burn Operations.

Research: Conduct large spill response exercise with real oil burn.
Method of Implementation: Field testing.
Priority: High
Comments: Although much has been learned about *in situ* burning through small scale tests and large scale tank burns, there are certain techniques and tactics which only can be evaluated in an open water response exercise with the actual burning of oil.

Research: Develop techniques for controlling and/or extinguishing burns.
Method of Implementation: Large scale tests and field trials.
Priority: High
Comments: *In situ* burn plans frequently include a provision to quickly terminate a burn due to either safety or environmental concerns. Several methods are frequently proposed for burns contained in a fire-resistant boom. One is to slowly increase the tow speed until the oil passes beneath the boom and is extinguished. A second method calls for the release of one end for the horseshoe shaped boom tow allowing the oil to spread to the point were burning can no longer be sustained. The actual use of these techniques has not been documented. Fire fighting foams are frequently used to control or suppress large flammable liquid fires; however, the use of these foams has not been investigated as a means of controlling an *in situ* burn.

Research: Increase the window of opportunity for *in situ* burning near shore or at the shoreline.
Method of Implementation: Large scale tests and burns of opportunity.
Priority: Medium/High
Comments: The impact of *in situ* burning on beaches in bays or other near shore areas has not been fully investigated. This could include the use of burn pits or pools to remove accumulated oil.

Research: Increase window of opportunity for burning on freshwater and upland burns.
Method of Implementation: Large scale tests and burns of opportunity.
Priority: Medium/High
Comments: Most *in situ* burns have taken place on fresh water or upland (on land). The impact of burning on these environments has not been fully quantified. Information on the impact of fire on vegetation has been developed for wildland fires but not for the fire intensity expected from *in situ* burning of oil.

Research: Determine distances for burn relative to oil slicks and other resources.
Method of Implementation: Analysis and large scale tests.
Priority: Medium/High
Comments: The ability of an *in situ* burn to ignite distant oil slicks has not been fully investigated. This is particularly important when burning near newly discharged "fresh" oil which has a low flash point.

Research: Increase the window of opportunity for *in situ* burning of uncontained or naturally contained oil.
Method of Implementation: Large scale tests and burns of opportunity.
Priority: Medium
Comments: The one most common uses of *in situ* burning to date involves uncontained or naturally contained oil. Uncontained or naturally contained oil could include spills on land (upland), in small bodies of water, in wetlands, or in ice. There is a need for better documentation of actual *in situ* burns. The burning of large uncontained spills on open water has not been extensively studied.

Research: Provide adequate worker safety.
Method of Implementation: Not applicable.
Priority: Further research on this topic is not a priority at this time.
Comments: The issue of worker health and safety has been addressed in the *in situ* burn site safety plan developed by the National Response Team (NRT). Since *in situ* burning may be implemented with fresh oil, a general site safety plan which addresses worker exposure to oil vapors should be used.

Resources and Systems

Need: Develop resources and systems to enhance the use of *in situ* burning.

Research: Continue performance testing of fire-resistant oil spill containment boom.
Method of Implementation: Large scale tests.
Priority: High
Comments: Preliminary testing of fire-resistant booms has provided useful data on boom performance. It also has encouraged further product development by manufacturers. Testing will be necessary to evaluate new and improved fire booms. The ASTM Standard Guide for *In Situ* Burning of Oil Spills On Water: Fire-Resistant Containment Boom is still a draft and final evaluation criteria have not been implemented.

Research: Develop fire-resistant booms for use in rivers.
Method of Implementation: Design and large scale tests.
Priority: Medium/High
Comments: Fire-resistant boom designed for use in open water may not be appropriate for use in flowing rivers. Presently there is no fire-resistant boom specifically designed for use

in swift water. In addition to a fire-resistant river boom, the use of temporary sheet steel deflection/containment “fences” may be advantageous.

Research: Develop application systems for emulsion breakers.
Method of Implementation: Design and operational testing.
Priority: Medium
Comments: In order to be effective, emulsion breakers must be applied uniformly and at the proper dosage. Dispersant application systems may not be appropriate or may require modification to be used with emulsion breakers.

Research: Develop a small scale pre-screening fire performance test for fire boom.
Method of Implementation: Small scale tests.
Priority: Medium
Comments: Prototype fire booms are expensive to test at full scale. The ability to examine new designs with a small scale test may encourage the development of new products.

Research: Enhance the use of fire-resistant boom to protect resources.
Method of Implementation: Design and large scale tests.
Priority: Medium
Comments: One of the potential uses of fire-resistant boom is to keep unintentionally ignited oil burning on water away from people and resources such as piers, docks, vessels and historical sites. The strategy may involve containing or deflecting the burning oil and letting it burn out, or containing the burning oil to increase fire fighting effectiveness. There may be a need to coordinate fire fighting operations with the application of fire-resistant boom used to protect resources.

Research: Develop modular incinerator or burn barge.
Method of Implementation: Design and large scale tests.
Priority: Low
Comments: There have been a number of studies and proposals for the development of incinerator and collection/incinerator barges. The barges are frequently designed to generate less visible smoke than burning in a fire-resistant boom. The benefit of these devices has not been clearly demonstrated since the cost and maintenance are high.

Water-in-oil Emulsions

Need: Increase operational window for burning water-in-oil emulsions.

Research: Cataloging of oils describing the tendency to form water-in-oil emulsions, emulsion burnability and suitability for use with emulsion breakers.
Method of Implementation: The approach should expand existing knowledge of burning water-in-oil emulsions with small scale and possibly large scale tests.
Priority: Medium/High
Comments: This work should include imported as well as North American oils. It may be desirable to include some heavy oils in these studies. Since it is difficult to characterize the oil at the time of a spill, it would be desirable to include oil burn properties (e.g., tendency to form emulsion, emulsion stability, suitable emulsion breakers) as part of the shipping information. Presently there are no emulsion breakers on the National Contingency Plan (NCP) product schedule. The addition of these items to the schedule needs to be addressed.

Research: Develop field kit for assessing the burnability of water-in-oil emulsions.
Method of Implementation: Not determined.
Priority: Low/Medium
Comments: Operating personnel desire a quick pre-burn assessment kit to enable them to determine if a water-in-oil emulsion is burnable. Although collecting a representative oil sample is difficult, a relatively simple test would be extremely valuable.

Research: Assess the effect of dispersants on *in situ* burning, particularly the use of dispersants on water-in-oil emulsions.
Method of Implementation: Laboratory and large scale experiments.
Priority: Low
Comments: Dispersants may serve as emulsion breakers in some cases but the impact on burning has not been assessed. Responders may consider burning the oil remaining after dispersants have been applied. They also may consider applying dispersants to the residue remaining after burning. The effect of dispersants has not been examined for these cases.

Research: Determine the effect of emulsion breakers or dispersants on *in situ* burn emissions.
Method of Implementation: Laboratory and large scale tests.
Priority: Low
Comments: The addition of chemicals to the spill may change the smoke composition during burning.

Environmental Factors

Need: Characterize the influence of environmental factors on *in situ* burning.

Research: Determine the effect of precipitation on burn efficiency.
Method of Implementation: Laboratory and large scale tests.
Priority: Low
Comments: Experience indicates that precipitation does not have a major impact on the burning rate of large oil fires; however, this has not been quantified.

Research: Study effects of debris on burning.
Method of Implementation: Large scale tests.
Priority: Low
Comments: Debris (e.g., vegetation, flotsam) may change the burning characteristics of the spill.

Non-Research and Development Needs

Action: Further develop training programs on *in situ* burning.
Method of Implementation: The panel made the following training recommendations:

- Ensure continued practice in boom operations to maintain proficiency in executing various configurations ("U" and "J") and station-keeping tactics.
- Exercise heli-torch systems with simulated oil spills.
- Structure training programs to include illustrations, photos and hands-on training activities.
- A suggested training curriculum may be structured as follows:
  1. A short (1 hr to 2 hr) introduction of *in situ* burning for management. Include defensive booming for protection from accidental fires.
  2. Hold one day of classroom training with lots of illustrations and photographs for the field responders.
  3. Conduct one to two days of field training including as much hands-on training as possible:
     a. Use of hand-held ignitors
     b. Small pan or bucket oil burning
     c. Boom deployments
     d. Fire suppression

Priority: High
Comments: The panel agreed there was no need for standard qualification of personnel at this time. The training needs to be tailored for different responder types (e.g., incident commanders, field workers).

JOINT PANEL RECOMMENDATIONS

Non-Research and Development Needs

Need: Increase communication, training, and outreach on *in situ* burning.

Action: Develop and implement strategy to communicate to the public, the role of *in situ* burning in spill response in relationship to other available response measures.
Method of Implementation:

- Evaluate public perception of oil spills and *in situ* burning and how to communicate information more effectively.
  - Develop strategy with involvement from responders, government agencies, health experts, risk communicators, communication specialists, and other experts.
  - Develop materials that include core components while allowing adaption for geographical differences.
  - Build upon existing efforts of educational materials such as those developed by the Alaska and Region I regional response teams (RRT).
- Provide information in different forms or formats appropriate for varying audiences including local fire departments, air quality boards, the fishing industry and Native American communities.
- Utilize large range of outlets to reach the span of "interested parties" (e.g., annual Continuing Challenge Meeting of Emergency Responders, TV documentaries, periodicals and newspaper articles, school curricula for different grade levels).

Priority: High
Comments: The group felt strongly that the lack of public education is a major impediment to implementation of *in situ* burning. This is in addition to the education of the response community (see below). As a consequence, the group felt that a core group should be established to motivate, track, and evaluate educational activities.

Action: Educate and train decision makers on role of *in situ* burning in spill response in the context of other available response measures.
Method of Implementation:

- Hold regional workshops with decision makers, including state air quality boards.
- Provide tools for risk communication, tradeoff analysis, and *in situ* burning plan development.
- Conduct drills with *in situ* burning scenarios including the Pollution Response Exercise Program (PREP).
- Analyze existing data on oil spill effects on air quality (e.g., ozone and non-attainment issues) and compare *in situ* burning and non-*in situ* burning consequences.

Priority: High
Comments: *In situ* burning needs to be endorsed at the highest levels of policy making, in order to insure that *in situ* burning is always considered as a possible response to oil spills. Decision

makers need to be clearly aware of the caveats and constraints of *in situ* burning operations and oil spill response. Furthermore, there needs to be frequent training and testing of knowledge to maintain preparedness and appropriate application of *in situ* burning options.

Action: Better communication and sharing of *in situ* burning information.
Method of Implementation: Using the Internet:

- Maintain and update *in situ* burning bibliography.
- Develop and synthesize questions and answers on *in situ* burning for different audiences.
- Post Regional Response Team's (RRT's) activities including *in situ* burning on RRT homepage sites.
- Establish and maintain List Server for sharing *in situ* burning information.
- Expand role of National Response Team, Science and Technology Committee (NRT/S&T) to provide focal point for *in situ* burn information.
- Provide generic spill "fact sheets" to complement incident specific websites.

Priority: Medium
Comments: The Internet offers new possibilities for sharing information, as well as incorporating information from recognized expert groups into tailored documents. This should be used to increase communication on this *in situ* burning and spill response in general.

IN SITU BURNING OF OIL SPILLS - WORKSHOP OVERVIEW

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SUMMARY

The Minerals Management Service (MMS) is designated as the lead agency for *In Situ* Burn (ISB) research in the Oil Pollution Research and Technology Plan, prepared under the authority of Title VII of the Oil Pollution Act of 1990. In January 1994, MMS sponsored a workshop, conducted by the National Institute of Standards and Technology (NIST), to determine the research needs required to advance the use of ISB in spill response. This workshop was one of MMS's effort's to ensure the relevance of their research program to the needs of the user community. Specific emphasis was given to environmental and operational implications of ISB response technology. The proceedings of the workshop[1] provide some insight into the remaining concerns of the industrial, government, and research organizations that participated.

In the four years since the first burn workshop, many research questions identified in the proceedings have been successfully addressed and answered. However, questions remain about the effects of ISB on both water and air quality. In addition, equipment to conduct burns such as durable fire resistant booms and the ability to extend the window of opportunity to use burning as the oil weathers and emulsifies is lacking. This workshop is a follow-up to the one conducted in 1994 and will include an update on the current state of burning and include breakout sessions to determine future research needs.

INTRODUCTION

In Situ Burning (ISB) of oil is not a new idea. The *Torrey Canyon* incident (1967) in Great Britain was the first major oil spill in which burning was attempted. However, due to the emulsification of the oil, results were unsuccessful and discouraged others from trying. During the 1970's and 1980's, there were many research studies and experimental burns conducted on ISB, including one successful burn conducted during the *Exxon Valdez* (1989) oil spill, but results have been varied. In 1983, the Minerals Management Service (MMS) initiated an ISB program to evaluate the burning of oil in different environments. This research has focused on the burning characteristics of crude oil fires on water, the composition of the combustion products and the dispersion and settling of particulate matter (soot) contained in the smoke plume. Results from laboratory tests, mesoscale burn experiments in Mobile, AL (1991-1994), the Alaska Emulsion Burn Experiments, and the full-scale Newfoundland Offshore Burn Experiment (NOBE), continue to show that ISB is a rapid, effective, and environmentally safe means for removing large quantities of oil from the water's surface. Information from laboratory, mesoscale, and full-scale crude oil burns has contributed significantly to the understanding of the actual impact of oil spill burning. Burning, once regarded as a method of last resort, is now, one of the first response methods to be considered by authorities in case of spill.

BACKGROUND

The proceedings of the first ISB workshop, conducted in January 1994, contain prioritized research and information needs required to support decisions on the use of *in situ* burning of oil spills.[1] Concerns of high priority were:

a. Improve predictions of potential human health effects from *in situ* burning.

b. Evaluate existing and relevant plume models for use in planning and real time estimation.

c. Verify existing smoke plume models with real-time measurements, including compound specific measurements.

d. Evaluate different real-time monitoring instruments for PM10, including laboratory methods.

e. Test operational monitoring protocols.

f. Develop criteria, protocols and performance data for fire resistant boon and igniters presently available on the market.

g. Develop means to make heavy oils (Group 5, Bunker C) and emulsified oils easier to burn.

h. Determine the conditions under which unconfined oil can burn.

i. Determine the feasibility of burning on land, in marshes, and on beaches.

j. The ability to control/extinguish an *in situ* burn at sea.

k. Chemical agents that can be applied to enhance various elements of the burn, smoke suppression, breaking of emulsions and promotion of combustion.

A number of issues arose during this workshop that were identified as important, but were not specifically related to research and development (R&D) needs. It was important to capture these issues, but not dwell on them due to the limited time available in the workshop. These issues were:

a. Legal/regulatory constraints

b. Need for education of regulators, public and operational personnel

c. Burning of residual wastes (sorbents, debris, booms)

Based on the information provided at the workshop through presentations and in the discussions held at the breakout sessions, there are no significant road blocks to having ISB accepted as a viable response technique. When additional information becomes available from R&D efforts and regulators become comfortable with the knowledge base, the procedures and pre-approval process will continue to be refined.

PURPOSE OF THE WORKSHOP

In the past five years, significant advances in the *in situ* burning of oil spills have been made. ISB as a response tool for large marine oil spills has progressed from a demonstration burn during the *Exxon Valdez* spill in 1989 to an accepted response technique. The relatively short window of opportunity for implementing ISB requires that burn operations be pre-planned and pre-approved to ensure an adequate response to spill events. Proponents of burning believe that ISB shows great promise as a response technique and that the environmental tradeoff's (burning vs. unburned oil spills) strongly favor burning in many scenarios. Opponents of ISB do not view the issue in terms of environmental tradeoff's. They cite specific reasons (inadequate research, fear of combustion products and the lack of adequate information on the environmental and human health implications of the smoke and burn residue).

This workshop will serve to summarize and evaluate the current state of knowledge with regards to burning. It will allow proponents and opponents of ISB to work with the facts as they exist today and make decisions that are based on data, not opinions. This workshop is part of MMS's continuing effort to ensure maximum applicability and benefits of its cooperative research to the user community.

The workshop is organized into two major segments. First, we have assembled recognized experts in various aspects of *in situ* burning of spilled oil. These invited speakers will summarize and present the current state of knowledge in specific research areas. They also will present future research plans to improve our understanding of ISB. The target audience is decision makers from local, state and federal government agencies, responders, environmentalists, academia, and the user community. We have attempted to involve regulatory and scientific agencies and the public in the dialogue of this workshop.

In the second major part, following the presentations, participants will breakout into two panels, Burning Operations and Environmental and Human Health. We recognize that several potential issues overlap this distinction but will be addressed in the final consensus document. Panels will examine the information presented, determine a consensus, and develop a list of priority research needs. The proceedings of the workshop will be published as the official transmittal of workshop information and recommendations. The proceedings will contain the panel's consensus list of priority research needs and well as the individual technical paper presented. The results of the workshop will be used by MMS and other agencies as input to their planning of future research efforts.

REFERENCES

1. Jason, N. H. *In Situ* Burning Oil Spill Workshop Proceedings, NIST SP 867, U.S. National Institute of Standards and Technology, Gaithersburg, MD, 1994.

WINDOW OF OPPORTUNITY FOR *IN SITU* BURNING

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INTRODUCTION

Thick, fresh slicks can be ignited very quickly with devices as simple as an oil-soaked sorbent pad. *In situ* burning can remove oil from the water surface very efficiently and at very high rates. Removal efficiencies for thick slicks can easily exceed 90%. Removal rates of 2000 m^3/hr can be achieved with a fire area of only about 10,000 m^2 or a circle of about 100 m in diameter. The use of towed fire containment boom to capture, thicken and isolate a portion of a spill, followed by ignition, is far less complex than the operations involved in mechanical recovery, transfer, storage, treatment and disposal. However, there is a limited window of opportunity for using *in situ* burning with the presently available technology. This window is partly defined by the type of oil spilled and its evaporation rate; the prevailing meteorological and oceanographic conditions; and, the time it takes the oil slick to emulsify. Once water contents of stable emulsions exceed about 25%, most slicks are unignitable.

The purpose of this paper is to review the current knowledge of limitations imposed by oil slick properties, weather and sea conditions and operational/equipment factors on the use of *in situ* burning as a countermeasure for oil spills on water. Environmental impact limitations are not discussed. Much of the content of this paper is updated from an in-depth review of *in situ* burning produced for the Marine Spill Response Corporation (MSRC) in 1994[1]. Interested readers are encouraged to refer to the original report for fully-referenced details of the summary presented here.

THE FUNDAMENTALS OF *IN SITU* BURNING

Requirements for Ignition

In order to burn oil spilled on water, three elements must be present: fuel, oxygen and a source of ignition. The oil must be heated to a temperature at which sufficient hydrocarbons are vaporized to support combustion in the air above the slick. It is the hydrocarbon vapours above the slick that burn, not the liquid itself. There are two properties of an oil that are often used as an indication of its ignitability: flash point and fire point. The temperature at which the slick produces vapours at a sufficient rate to ignite is called the flash point. The fire point is the temperature a few degrees above the flash point at which the oil is warm enough to supply vapors at a rate sufficient to support continuous burning.

Heat Transfer Back to Slick

Most heat from a burning oil slick is carried away by the rising column of combustion gases, but a small percentage (about 1% to 3%) radiates from the flame back to the surface of the slick. This heat is partially used to vaporize the liquid hydrocarbons which rise to mix with the air above the slick and burn; a small amount transfers into the slick and eventually to the underlying water. Once ignited, a burning thick oil slick reaches a steady-state where the vaporization rate sustains the combustion reaction, which radiates the necessary heat back to the slick surface to continue the vaporization.

Flame Temperatures

Flame temperatures for crude oil burns on water[2] are about 900 °C to 1200 °C. But the temperature at the oil slick/water interface is never more than the boiling point of the water and is usually around ambient temperatures. There is a steep temperature gradient across the thickness of the slick; the slick surface is very hot (350 °C to 500 °C) but the oil just beneath it is near ambient temperatures.

Importance of Slick Thickness

The key oil slick parameter that determines whether or not the oil will burn is slick thickness. If the oil is thick enough, it acts as insulation and keeps the burning slick surface at a high temperature by reducing heat loss to the underlying water. This layer of hot oil is called the "hot zone". As the slick thins, increasingly more heat is passed through it to the water; eventually enough heat is transferred through the slick to allow the temperature of the surface oil to drop below its fire point, at which time the burning stops.

Oil Burning Rates

The rate at which *in situ* burning consumes oil is generally reported in units of thickness per unit time (mm/min is the most commonly used unit). The removal rate for *in situ* oil fires is a function of fire size (or diameter), slick thickness, oil type and ambient environmental conditions. For most large (> 3 m diameter) fires of unemulsified crude oil on water, the “rule-of-thumb” is that the burning rate is 3.5 mm/min. Automotive diesel and jet fuel fires on water burn at a slightly higher rate of about 4 mm/min.

Factors Affecting Quantity of Residue and Burn Efficiency

Oil removal efficiency is a function of three main factors: the initial thickness of the slick; the thickness of the residue remaining after extinction; and, the areal coverage of the flame. The general rules-of-thumb for residue remaining after a successful burn are described below. Other, secondary factors include environmental effects such as wind and current herding of slicks against barriers and oil weathering.

The following rules-of-thumb apply for the residue thickness at burn extinction:

- for pools of unemulsified crude oil up to 10 mm to 20 mm in thickness the residue thickness is 1 mm;
- for thicker crude slicks the residue is thicker, for example, 3 mm to 5 mm for 50 mm thick oil;
- for emulsified slicks the residue thickness can be much greater; and,
- for light and middle-distillate fuels the residue thickness is 1 mm, regardless of slick thickness.

The residue from a typical, efficient (>85%) *in situ* burn of crude oil 10 mm to 20 mm thick is a semi-solid, tar-like layer that has an appearance similar to the skin on a poorly sealed can of latex paint that has gelled. For thicker slicks, typical of what might be expected in a towed fire boom (about 150 mm to 300 mm), the residue can be a solid. The cooled residue from thick (>100 mm), efficient *in situ* burns of heavier crude oils can sink in fresh and salt water[3] .

Flame Spreading

Flame spreading is a crucial aspect of effective *in situ* burning. If the fire does not spread to cover a large part of the surface of a slick, the overall removal efficiency will be low. There are two ways in which flames spread across a pool of liquid fuel: radiant heating of the adjacent liquid oil warms it to its fire point, and the hot liquid beneath the flame spreading out over the surrounding cold fuel.

As oil evaporation (or weathering) increases, flame spreading velocity decreases. The reason for this is that the difference between ambient temperature and the oil's flash point increases, requiring additional heating to raise the temperature of the slick surface. Flame spreading speeds increase with increasing slick thickness due to the insulating effect of the oil layer. For a constant slick thickness and flash point, increasing viscosity reduces flame spreading speed. Downwind flame spreading increases with increasing wind speed. This is likely due to the bending of the flame by the wind enhancing heating of the slick. Flames tend to spread straight downwind from the ignition point without significant crosswind spread. Flame spreading upwind is slow, although the presence of a barrier or edge that provides a wind break can permit rapid upwind or cross-wind spreading. The presence of current and regular waves (or swell) does not seem to affect flame spreading for unemulsified oils, but choppy or steep waves have been noted to curtail flame spreading.

LIMITATIONS TO SUCCESSFUL *IN SITU* BURNING IMPOSED BY SLICK PROPERTIES

Effect of Evaporation on Slick Ignition

Extensive experimentation on crude and fuel oils with a variety of igniters in a range of environmental conditions has confirmed the following "rules-of-thumb" for relatively calm, quiescent conditions:

- the minimum ignitable thickness for fresh, volatile crude oil on water is about 1 mm;
- the minimum ignitable thickness for aged, unemulsifed crude oil and diesel fuels is about 2 mm to 5 mm;
- the minimum ignitable thickness for residual fuel oils, such as Bunker "C" or No. 6 fuel oil, is about 10 mm; and,
- once 1 m^2 of burning slick has been established, ignition can be considered accomplished.

Other Factors Affecting Successful Ignition

Aside from oil type, other factors that can affect the ignitability of oil slicks on water include wind speed, emulsification of the oil and igniter strength. Secondary factors include ambient temperature and waves.

- The maximum wind speed for successful ignition of large burns has been determined to be 10 m/s to 12 m/s.
- If the ambient temperature is above the oil's flash point, the slick will ignite rapidly and easily and the flames will spread quickly over the slick surface; flames spread more slowly over oil slicks at sub-flash temperatures.

Effects of Water-in-oil Emulsion Formation

Emulsification of an oil spill negatively affects *in situ* ignition and burning. This is because of the water in the emulsion. Stable emulsion water contents are typically in the 60% to 80% range with some up to 90%. The oil in the emulsion cannot reach a temperature higher than 100 °C until the water is either boiled off or removed. The heat from the igniter or from the adjacent burning oil is used first mostly to boil the water rather than heat the oil to its fire point.

A two-step process is likely involved in emulsion burning: "breaking" of the emulsion, or possibly boiling off the water, to form a layer of unemulsified oil floating on top of the emulsion slick; and subsequent combustion of this oil layer. High temperatures are known to break emulsions. Chemicals called "emulsion breakers", which are common in the oil industry, also may be used.

For stable emulsions the burn rate declines significantly with increasing water content. The reduction in burning rate with increasing water content is decreased further by evaporation of the oil. The effect of water content on the removal efficiency of weathered crude emulsions can be summarized by the following rules-of-thumb:

- little effect on oil removal efficiency (i.e., residue thickness) for low water contents up to about 12.5% by volume;
- a noticeable decrease in burn efficiency with water contents above 12.5%, the decrease being more pronounced with weathered oils; and
- zero burn efficiency for stable emulsion slicks having water contents of 25% or more. Some crudes form meso-stable emulsions that can be burn efficiently at much higher water contents. Paraffinic crudes appear to fall into this category[4].

Compared to unemulsified slicks, emulsions are much more difficult to ignite and, once ignited, display reduced flame spreading and more sensitivity to wind and wave action.

Emulsion Breakers

The idea of applying emulsion breakers to a slick to break the emulsion *in situ*, remove water, and extend the window of opportunity for successful ignition of the slick is being actively researched. Recent large-scale tests in Alaska[5,6], the U.K.[7] and Norway[8,9] indicate that the technique shows great promise, although there is strong evidence that the technique is highly oil-specific and surfactant-dependant.

A recently-completed study of emulsion burning with Alaskan oils[6] is summarized below to illustrate the potential for chemical treatment to extend the window of opportunity for *in situ* burning and the challenges remaining.

Four oils were selected for an initial set of quiescent laboratory test burns (40 cm diameter): Drift River crude from Cook Inlet, Endicott and Pt. McIntyre crudes from the North Slope, and IF-30, a common bunker fuel for vessels. As expected, the ignition and burning of all four oils was limited by the formation of water-in-oil emulsions. As has been noted in other studies[10,11], the burning of emulsions *in situ* was found to be oil-specific, with some oils (e.g., Drift River - see Table 1 below) being much easier to ignite and burn than others (e.g., Pt. McIntyre). Evaporation also appeared to play a strong role in emulsion burning; increased weathering decreased ignitability and burn efficiency. Increased water content also reduced ignitability, oil burn rate and burn efficiency. The application of chemical breakers to emulsions of the four oils extended the limits of ignition and burning. The efficacy of emulsion breaker addition in extending the limits of ignition and efficient burning appeared to be oil-related. The use of an emulsion breaker considerably extended the limits for some oils (e.g., Drift River) but only had a marginal effect on others (e.g., Pt. McIntyre).

Table 1: Efficacy of emulsion breaker addition summary

Oil Type	**Maximum Ignitable (% weathered/% water)**	**Maximum Ignitable with Emulsion Breaker Added (% weathered/% water)**
Drift River crude	35.4% evap. / 25% H_2O	35.4% evap. / 60% H_2O
Endicott crude	fresh / 25% H_2O	9.1% evap. / 60% H_2O
Pt. McIntyre crude	fresh / 25% H_2O	fresh / 40% H_2O 18.2% evap. / 25% H_2O
IF-30 fuel oil	fresh / 25% H_2O	fresh / 40% H_2O
Milne Pt. crude		
- lab scale	40.7% evap. / 60% H_2O	40.7% evap. / 60% H_2O
- mid scale	27.6% evap. / 60% H_2O	27.6% evap. / 60% H_2O
ANS crude		
- lab scale*	28% evap. / 25% H_2O	28% evap. / 60% H_2O
- mid scale	20.4% evap. / 25% H_2O	20.4% evap. / 60% H_2O

In situ burning of emulsions also was sensitive to ambient temperature. Generally, at higher temperatures, ignition of emulsions became easier and burn efficiency increased. This effect appeared to be oil-specific as temperature increases had large effects on the burning of emulsions of some oils (e.g., Drift River and Endicott) but almost no effect on others (e.g., Pt. McIntyre).

For the lab-scale burns (40 cm diameter) in wave conditions of normally unignitable emulsions of ANS, the addition of a chemical breaker was successful in promoting emulsion ignition. Manually mixing the emulsion breaker chemical was found to be somewhat more effective than the natural mixing of the emulsion breaker with wave action alone. The results indicated that mixing energy supplied either manually or by the waves was necessary for the chemical to work.

The small-scale lab tests with the Milne Pt. crude revealed that it has a low to moderate tendency to form emulsions and their tendency and stability increased with degree of weathering; it responded well to treatment with emulsion breakers; it was highly ignitable and burned readily, even at high degrees of weathering and with high emulsion water contents; and, it burned well in waves.

The mid-scale (1.7 m diameter) burn tests, in a newly-constructed wave tank in Prudhoe Bay, showed that larger oil and emulsion slicks of ANS and Milne Pt. crudes could be successfully burned in waves. Emulsified slicks of ANS crude with water contents greater than 25% required treatment with emulsion breakers and a period of settling for successful ignition and efficient burning. The Milne Pt. emulsions ignited and burned easily without treatment. A mid-scale test slick of 60% water emulsion of weathered ANS crude was successfully burned in the highest waves tested, with an oil removal efficiency of 79%, after treatment with emulsion breakers. A similar test slick of 60% water emulsion of weathered Milne Pt. crude was successfully burned in the highest waves tested, without the need for treatment with emulsion breakers, with an oil removal efficiency of 83%. At this larger scale, increasing wave steepness (or wave energy) appeared to reduce both burn rates and burn efficiencies of the unemulsified oil slicks. For emulsified slicks, increasing wave steepness did not appear to appreciably affect the oil burning rates, but did reduce the oil removal efficiencies.

The results of this research have indicated that the concept of applying emulsion breakers to extend the window of opportunity for i*n situ* burning still has merit. It is clear that the efficacy of the technique is dependant on oil type and degree of weathering. It was also dependant on the specific emulsion breaker used.

The results of the study are not, in themselves, sufficient to conclude that the operational use of emulsion breakers offshore is feasible. In order to implement emulsion breaker addition as a technique to extend the window of opportunity for *in situ* burning (ISB) operations offshore several areas still need to be researched. These include:

- exploring the regulatory regimes covering the application of emulsion breakers to oil slicks, and, if required, obtaining approval for specific chemicals being considered for ISB;

- investigating and developing systems for the application, and perhaps mixing, of emulsion breakers at dose rates on the order of 1:500 onto contained slicks at sea;

- conducting large-scale trials in realistic wave conditions (i.e., on the order of 0.6 m to1 m high) to fully prove the operational feasibility of burning water-in-oil emulsions *in situ*. Although ideally these trials should be conducted at sea, tests in a large pit or other water body could serve as a substitute. These tests are necessary to confirm that in an offshore environment the emulsion breaker can be applied and work effectively over a large area of slick; that the flames will spread from an area ignited with a heli-torch to cover the entire slick; and, that an efficient burn will result that removes a significant amount of the oil.

Other research programs underway on the subject of burning water-in-oil emulsions *in situ* include small-scale testing of a number of crude oils produced on the Outer Continental Shelf of the United States to determine their burning characteristics[10,11], studies of the fundamentals of emulsion burning[12], and studies of the ignition and flame spreading characteristics[13] of emulsions.

LIMITATIONS TO *IN SITU* BURNING IMPOSED BY OPERATIONAL CONSTRAINTS

There are two basic scenarios for the application of controlled *in situ* burning in spill response operations: the "batch" mode and the "continuous" mode. The "batch" mode consists of six discrete steps: 1) oil is collected in a section of fire-resistant boom towed by two vessels until the back third of the boom is filled; 2) the filled boom is manoeuvered to a safe distance crosswind; 3) the contained oil is ignited; 4) the oil is burned and then extinguishes; 5) the residue is collected, if necessary and the boom inspected for damage, and replaced if necessary; and, 6) the boom is maneuvered back into the slick to begin collecting the next batch of oil.

In the "continuous" mode the fire-resistant boom is positioned a safe distance down drift from a continuing oil leak, such as a blowout, and oil is burned continuously or intermittently as it accumulates in the back of the boom. An alternative to controlled burning is the ignition of uncontained oil slicks that are thick enough to support combustion.

Capabilities and Limitations

The oil removal rate for the "batch" mode is constrained by the rate at which the towed boom can encounter oil (estimated from the tow speed--a maximum of 0.35 m/s, the width of the mouth of the boom and the average thickness of the slick through which the boom is being towed); and, the time required to manoeuver the boom to a safe area, ignite and burn the oil, recover the residue, inspect and perhaps replace the boom, and return to the oil collection area[14]. The oil removal rate for the "continuous" mode is constrained by the rate at which the boom system collects the leaking oil and the ability to keep the boom on station in the oil slick.

There is limited data on the effects of sea state on *in situ* burning What little experience exists suggests that the sea-state limit for effective burning is from 1 m to 2 m significant wave height or less. Of course, burning will not be effective if the fire boom fails to hold oil in these sea conditions.

Winds of approximately 30 km/hr to 40 km/hr are considered to be the upper limit for ignition of oil pools in the absence of waves. These constraints reflect both the current state-of-the-art in proven ignition and fire containment booms systems, as well as the environmental conditions under which most oils will be quickly weathered beyond a combustible state.

Another important environmental factor controlling burning is the presence of good visibility. For a safe and effective burn to take place it should be possible to see 1) the oil to be collected, 2) the vessels towing the fire containment booms, and 3) the proximity of the intended burn location relative to the spill source, other vessels in the area, and other potentially ignitable slicks. As a guide, VFR (visual flight rules) flying conditions (greater than 4 km visibility and a minimum 300 m ceiling) could be used. If helicopters are to be used, VFR flying conditions must exist both at the site and at the helicopter base. If burning is to be conducted at a remote, fixed, continuous source of spilled oil (e.g., an offshore blowout), it may be feasible to burn spilled oil safely at or near the source during limited visibility conditions (e.g., less than VFR flying conditions, dusk, dawn, etc.).

THE FUTURE

In situ burning is a potentially valuable tool for oil spill response. If used prudently, it can make a significant contribution as one facet of an overall spill response operation. For spills in ice-covered waters it may be the only removal option. Although a considerable body of knowledge exists on the use and impacts of *in situ* burning, continued research is warranted, particularly on better understanding the fundamentals of emulsion burning; developing catalogues of the *in situ* burning characteristics of various oils; the use of emulsion breakers to extend the window of opportunity; and, developing better, longer-service-life fire containment booms.

Most importantly, *in situ* burning needs to be used on real spills; it is only through operational usage that practitioners will gain the knowledge to ascertain the place of burning in an overall oil spill response.

REFERENCES

1. Buist, I.A. ,S.L. Ross, B.K. Trudel, E. Taylor, T.G. Campbell, P.A. Westphal, M.R. Myers, G.S. Ronzio, A.A. Allen and A.B. Nordvik. The Science, Technology and Effects of Controlled Burning of Oil Spills at Sea. MSRC Technical Report Series 94-013, Marine Spill Response Corporation, Washington, DC., 382 p., 1994.

2. Fingas, M.F. ,G. Halley, F. Ackerman, R. Nelson, M. Bissonnette, N. Laroche, Z. Wang, P. Lambert, K. Li, P. Jokuty, G. Sergy, E.J. Tennyson, J. Mullin, L. Hannon, R. Turpin, P. Campagna, W. Halley, J. Latour, R. Galarneau, B. Ryan, D.V. Aurand and R.R. Hiltabrand, The Newfoundland Offshore Burn Experiment - NOBE. Proceedings of the 1995 Oil Spill Conference, American Petroleum Institute, Washington, D.C. pp 123-132, 1995.

3. SL Ross Environmental Research Ltd. Laboratory Studies of the properties of *in situ* burn residues. Marine Spill Response Corp. Technical Report Series 95-010. Herndon, VA, 1996.

4. Fingas, M.F., B. Fieldhouse and J.V. Mullin. Studies of Water-in-oil emulsions: Stability studies. Proceedings of the Twentieth Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, ON, pp 21-42, 1997.

5. SL Ross Environmental Research Ltd. Demulsifiers and modified heli-torch fuels to enhance *in situ* burning of emulsions. Report to Alaska Clean Seas, Anchorage, AK, 1995.

6. SL Ross Environmental Research Ltd. The efficacy of *in situ* burning for Alaskan risk oils. Report to Alaska Department of Environmental Conservation and Alaska Clean Seas. Juneau, AK, 1998.

7. Thornborough , J. United Kingdom *in situ* burning trials, Lowescroft, Proceedings of the 1997 Oil Spill Conference, American Petroleum Institute, Washington, D.C. pp 131-136, 1997.

8. Guenette, C., P. Sveum, C. Bech, and I. Buist. Studies of *in situ* burning of emulsion in Norway. Proceedings of the 1995 Oil Spill Conference, American Petroleum Institute, Washington, D.C. pp 115-123, 1995.

9. Guenette, C., and R. Wighus. *In situ* burning of crude oil and emulsions in broken ice. Proceedings of the Nineteenth Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, ON, pp 895-906, 1996.

10. McCourt, J. I. Buist and J. Mullin. Laboratory testing to determine operational parameters for *in situ* burning of six U.S. Outer Continental Shelf crude oils. Proceedings of the Twenty-first Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, ON, pp 623-632, 1998.

11. SL Ross Environmental Research Ltd. Laboratory testing to determine operational parameters for *in situ* burning of six more U.S. Outer Continental Shelf crude oils. Work in progress for MMS, Herndon, VA, 1998.

12. Walavalkar, A. and A.K. Kulkarni. A mathematical model for *in situ* burning of water-in-oil emulsions. Proceedings of the Twentieth Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, ON, pp 809-822, 1997.

13. Wu, N., M. Baker, G. Kolb and J.L. Torero. Ignition, flame spread and mass burning characteristics of liquid fuels on a water bed. Proceedings of the Twentieth Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, ON, pp 769-794, 1997.

14. SL Ross Environmental Research Ltd., A review of *in situ* burning as a response for spills of Alaska North Slope crude oil in Prince William Sound. Prince William Sound Regional Citizens Advisory Council, Anchorage, AK, 1997.

STATUS OF FIRE BOOM PERFORMANCE TESTING

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SUMMARY

Most response plans for *in situ* burning of oil at sea call for the use of a fire-resistant boom to contain the oil during a burn. Presently, there is no standard method for the user of a fire-resistant boom to evaluate the anticipated performance of different booms. The American Society for Testing and Materials (ASTM) F-20 Committee has developed a draft Standard Guide for *In Situ* Burning of Oil Spills On Water: Fire-Resistant Containment Boom; however, the draft provides only general guidelines and does not specify the details of the test procedure. Significant advances have been made in the past three years in implementing the guidelines in the draft standard. Two series of tests, one using diesel fuel and one using propane, have been conducted to evaluate the protocol for testing the ability of fire-resistant booms to withstand both fire and waves. A brief description and comparison of these tests is presented along with a discussion of the strengths and weaknesses of the use of each fuel and some issues identified in the tests.

INTRODUCTION

In situ burning of spilled oil has distinct advantages over other countermeasures. It offers the potential to convert large quantities of oil into its primary combustion products, carbon dioxide and water, with a small percentage of smoke particulate and other unburned and residue byproducts. *In situ* burning requires minimal equipment and less labor than other techniques. It can be applied in areas where many other methods cannot be used due to lack of a response infrastructure and/or lack of alternatives. Because the oil is mainly converted to airborne products of combustion by burning, the need for physical collection, storage, and transport of recovered fluids is reduced to the few percent of the original spill volume that remains as residue after burning.

Oil spills on water naturally spread to a thickness where the oil cannot be ignited or burning sustained. It has been found that a minium oil thickness of 1 mm to 5 mm is required for ignition depending on the nature of the oil[1]. As a result, the scenarios which have been developed for *in situ* burning of oil on water include some means for corralling the oil. The use of fire-resistant containment boom is the method most often proposed for maintaining adequate oil thickness to support burning. In that scenario, oil is collected from the spill in a horseshoe or catenary-shaped boom towed by two vessels. Once an adequate quantity of oil has been collected from the spill, the oil is ignited and burned while being towed in the boom. The oil is maintained at a sufficient thickness in the apex of the boom to support burning until nearly all of the oil is consumed. The process of collecting and burning can then be repeated. For this scenario to be successful, the boom must be capable of withstanding repeated fire exposures while containing the oil.

BACKGROUND

Oil spill planners and responders need to know the expected performance of fire-resistant oil spill containment boom. This need has been addressed through either at-sea demonstration tests, tests in a pan or tank with static water, or tests in a wave tank. The focus of this presentation is on fire performance and not the oil collection performance. Methods for evaluating the oil collection performance have been reported previously[2].

Ideally, a test method should provide a measure of performance of the item being tested. The measure should be related in one or more ways to the anticipated use of the item. One method is a test which replicates as closely as possible actual use conditions. This method is perhaps the easiest to understand and most commonly considered, but lacks flexibility. Unless there is a single use condition, a number of test conditions may be required to replicate all possible uses. A second method is a test which measures properties of the item. If the relationship between the properties and the use conditions is known, the performance under a variety of conditions could be predicted.
Two important aspects of a test method are repeatability and reproducibility. Repeatability is the ability to obtain acceptably similar test results for the same item at a given location. Reproducibility is the ability to obtain acceptably similar test results for a given item at different test locations. Factors which affect repeatability and reproducibility are the control of test parameters and operator bias. Repeatability and reproducibility are often analyzed using statistical methods with a number of tests using multiple items and several test locations.

At the present time, there is not an adequate understanding to develop a test which would relate boom component properties to the performance of a boom in actual use. Further, a component property test method would have to be compared with the performance of a complete boom to determine its ability to predict performance. This leads to the choice of a test which replicates the conditions to which a fire-resistant oil spill containment boom would be exposed during the oil burning phase of its deployment.

One candidate test method would be to deploy a boom at sea under prescribed conditions, corral a specified quantity of oil, burn the oil and observe the performance of the boom. While this procedure would most closely replicate actual use conditions, it would be very expensive and require environmental permits which are difficult to obtain in most areas. A few at-sea tests with fire-resistant oil spill containment boom have been conducted; most notably was the NOBE (Newfoundland Offshore Burn Experiment) burn in 1993.

Temporary oil containment areas in thick ice have been used in some countries to conduct oil spill research, but the permits required in the United States appear to be the same as those for open waters. A related possibility would be to use actual oil spills or so-called “spills of opportunity.”

Fortunately, oil spills are fairly rare occurrences and the opportunity to conduct standardized tests, with a number of booms during a spill, would be an even rarer event.

This leaves a land-based containment tank as the best choice for the evaluation of the fire performance of a number of booms. There are a number of containment areas, pits, tanks or pans which are designed and permitted for burning liquid fuels. Most of these are fire training areas and some have been used in the past to evaluate fire-resistant booms. However, these do not have the capability to produce waves which are considered an important aspect in evaluating fire-resistant boom. Wave tanks designed for oil spill research are generally not designed to withstand a fire and the environmental permits necessary for burning may be unavailable for these sites.

DESIGN OF TEST PROCEDURE

The ASTM F-20 Committee has developed a draft Standard Guide for *In Situ* Burning of Oil Spills On Water: Fire-Resistant Containment Boom. The draft standard could be considered a guideline since it does not provide all of the specific details necessary to conduct an evaluation of fire-resistant boom. It does, however, provide some general performance requirements related to the collection and burning of oil. Since it is a draft document under development, the standard continues to be revised. The principal burn related feature of the draft calls for a burn exposure, cool down cycle consisting of one hour of burning followed by one hour with no burning, followed by one hour of burning and one hour of no burning followed by one hour of burning. This is a total of 3 one hour burn periods and 2 one hour cool down periods. The wave characteristics to which the boom would be exposed during burning and cooling and the boom configuration were not specified.

Two principal approaches have been used in North America. One uses liquid fuel (diesel fuel) for the exposure fire and the other uses gaseous fuel (propane) for the exposure fire. The philosophy in developing these test procedures was to subject a boom to conditions which could be used to evaluate the performance of the boom when used for *in situ* burning during a spill response. The ASTM draft standard served as guidelines in developing the procedures, but there also were environmental, engineering and economic constraints.

There are advantages associated with the use of either diesel fuel or propane. Diesel fuel fires closely represent crude oil fires in intensity; the fuel can be absorbed by the boom material, and diesel fuel is relatively easy to transport and store. Propane fires produce little visible smoke, can be started and stopped quickly, the area of the fire can be easily controlled without containment, and there is no residue. Although propane appears to be the most attractive fuel, the principal disadvantage is the heat flux from a propane diffusion fire to the boom is about one half that from a large diesel fuel fire[3]. In order to generate a comparable heat flux with propane, air must be added to the flames.

DIESEL FUEL TESTS

Fire boom test evaluations using diesel fuel were conducted in 1997 and 1998 by the National Institute of Standards and Technology (NIST), and sponsored by the U.S. Coast Guard Research and Development Center and the U.S. Minerals Management Service, Technology Assessment and Research Branch. The test evaluations were conducted in a wave tank designed specifically for evaluating fire-resistant boom located at the U.S. Coast Guard Fire and Safety Test Detachment facility on Little Sand Island in Mobile Bay, Alabama[4]. The wave tank was constructed of steel and was 1.5 m deep with two perimeter walls 1.2 m apart forming an inner and outer area of the tank. The inside dimensions of the inner area of the tank were 30.5 m by 9.1 m. The wave tank was designed to accommodate a nominal 15 m boom section forming a circle approximately 5 m in diameter. The heat flux at the base of a liquid pool fire and the burning rate are functions of the fire diameter. The heat flux and the burning rate increase with increasing fire diameter for small fires. Once the diameter reaches 5 m, the heat flux and burning rate are nearly constant as the fire diameter increases. Thus, the fire within the boom containment would be large enough to represent the thermal exposure from a larger fire.

A suspended paddle wave maker was used to produce 0.3 m high waves with a period of 3 s to 5 s at a water depth of 1.2 m. The wave energy was dissipated with a sloping beach at the end of the tank.

The boom was kept in position during the test by 6 boom constraints or stanchions. The stanchions were mounted vertically in a pattern forming a circle around the center of the tank either inside or outside the boom circle. If the stanchions were located outside the boom circle, cables were used to connect the boom to the stanchions.

The fuel used for the tests was number 2 diesel fuel. The fuel was stored in a storage tank and pumped to the boom circle via an underground piping system. The fuel entered the center of the tank under water and floated to the water surface.

Tests series were conducted in this tank in 1997 with 5 booms and in 1998 with 6 booms. A complete description of the 1997 tests can be found in reference [4]. A photograph of the wave tank with a burn in progress is shown in figure 1.

Figure 1. Diesel fuel test

PROPANE FUEL TESTS

Fire boom test evaluations using propane were conducted in 1996 and 1997 by SL Ross Environmental, Ltd, and sponsored by the Canadian Coast Guard and the U.S. Minerals Management Service, Technology Assessment and Research Branch. The propane test evaluations were conducted in a wave tank located at the Canadian Hydraulic Centre, National Research Council of Canada in Ottawa. The wave tank was constructed of concrete and was 120 m long by 60 m wide by 3.3 m deep. A pneumatic wave maker at one end of the tank could be used to generate waves up to 0.6 m in height although waves 0.34 m high with a period of 2 s were used for the tests. The wave energy was dissipated with a sloping beach at the end of the tank.

In the 1996 tests, a section of boom 14.6 m long was placed in a catenary shape. The ends of the boom were secured with cables and the shape was maintained with a current created with water jets. In the 1997 tests, the section of boom was oriented in a line along the direction of wave travel and held in place with tensioning cables.

The fuel used for the tests was commercial propane. Liquid propane from a storage tank was heated to create gaseous propane and piped to an underwater bubbling system. Flames were applied to both sides of the boom to simulate the exposure observed in the diesel fuel tests and the NOBE experiment where flames were observed on both sides of the boom at the apex. In the 1996 tests, propane alone was used. In the 1997 tests, compressed air was injected into the flames through nozzles around the boom. In the 1996 tests with propane only, the heat flux measured at the boom was substantially less than the heat flux measured at the boom in the diesel fuel fires. In the 1997 tests with air injected into the flames, the heat flux was comparable to that measured in the diesel fuel fires.

A complete description of the 1996 and 1997 tests can be found in references[5,6]. A photograph of the wave tank with a burn in progress in the 1997 tests is shown in figure 2. Further tests with air-enhanced propane are planned for the fall of 1998 at OHMSETT, the National Oil Spill Response Test Facility, in New Jersey, which is operated by the Minerals Management Service.

Figure 2. Propane fuel test

GENERAL OBSERVATIONS

Although the diesel fuel and propane test development projects would appear to be in competition, this was not the case. There was significant cooperation on the part of the project engineers which included the exchange of data and visits to both test sites. The diesel fuel tests appear to most closely replicate conditions expected during the actual use of *in situ* burning. The diesel fuel tests provided valuable data and experience in conducting tests and served as a benchmark for the propane tests. Test results have been submitted to the ASTM F-20 Committee for use in developing the Standard Guide for *In Situ* Burning of Oil Spills On Water: Fire-Resistant Containment Boom. The tests also provided information to the boom manufacturers on the performance of their products.

In general, as would be expected, there was some degradation of materials in all of the booms with both fuels. Further, it appeared that many booms had not reached a steady-state condition in terms of degradation. That is, for many of the booms, if they had been subjected to further fire exposure, one would have expected further material degradation to take place. Since the principal purpose of these projects was to evaluate the test protocol, the booms were not rated as passing or failing.

Although two quite different methods of fuel delivery were used, the burn characteristics in both were influenced by the wind speed and direction. When the wind speed was low, the flames rose nearly vertically providing a relatively uniform thermal exposure to the boom. With increased wind speed, the most significant thermal exposure was observed to take place downwind of the flames. If the wind direction was relatively constant over the course of the three burns for a given boom, the same section of the boom received repeated thermal exposure. If the wind direction changed during the burns, differing sections of the boom received the most intense thermal exposure.

ISSUES AND CONCLUSIONS

Overall, the test protocol and its application were considered successful with both diesel fuel and air-enhanced propane. The propane fuel test method appears promising for future use, particularly since very little visible smoke is produced. Based on the results of these tests, several issues have been identified for possible further consideration. These issues include the following items not necessarily in order of importance.

1) Does the fire size and duration coupled with the wave action represent a realistic thermal and mechanical exposure? Although it is a largely subjective observation, the fire and wave exposures used in both the diesel fuel and propane tests appeared to provide a reasonable representation of the important features of actual *in situ* burn conditions. Presently, there are not adequate data available to compare the test performance to performance in an actual at-sea burn under given fire and wave conditions or compare the performance of all types of booms in the diesel fuel and propane tests.

2) How does wind speed and direction affect the thermal exposure to the boom? The impact of the wind speed and direction on the thermal exposure are difficult to quantify. Heat flux measurements around the boom would provide the best measure of thermal exposure, but these are difficult to attach to the boom and a significant number would be required to adequately profile the thermal exposure along the length of the boom. It may be appropriate to impose a constraint on wind speed during a test.

3) Should replicate tests be required? When evaluating a test method it usually is desirable to conduct multiple tests with the same product to determine if the method is repeatable. Production and prototype fire booms are expensive to manufacturer and the tests are expensive to conduct.

4) What evaluation criteria should be applied to the booms at the end of the test? The criteria for evaluating a boom is one of the most difficult and sensitive issues. One option is to report the condition of the boom, including attributes such as freeboard, which can be measured. In some cases, holes in the booms above the waterline were noted and the impact of these holes on the expected performance of the boom was difficult to judge. Therefore, it is unlikely that a numerical rating could be developed for these tests so a pass or fail criteria may be the best option.

REFERENCES

1. Buist, I.A., Ross, S.L., Trudel, B.K., Taylor, E., Campbell, T.G., Westphal, P.A., Myers, M.R., Ronzio, G.S., Allen, A.A., and Nordvik, A.B., The Science, Technology and Effects of Controlled Burning of Oil Spills at Sea, Marine Spill Response Corporation, Washington, D.C., MSRC Technical Report Series 94-013, 328p., 1994.

2. Bitting, K. and Coyne, P.M., Oil Containment Tests of Fire Booms, Proceedings of the Twentieth Arctic and Marine Oilspill Program (AMOP), Environment Canada, Ottawa, Ont., pp. 735-754, 1997.

3. Walton, W., McElroy, J., Twilley, W., and Mullin, J., An Evaluation of Propane as a Fuel for Testing Fire-Resistant Oil Spill Containment Booms, Proceedings of the Twentieth Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada, Ottawa, Ont., pp. 755-767, 1997.

4. Walton, W., Twilley, W., Hiltabrand, R., and Mullin, J., Evaluating a Protocol for Testing Fire-Resistant Oil Spill Containment Boom, Proceedings of the Twenty-First Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada, Ottawa, Ont., pp. 651-671, 1998.

5. McCourt, J., Buist, I. Pratte, B., Jamieson, W., and Mullin, J., Testing Fire Resistant Boom in Waves and Flames, Proceedings of the Twentieth Arctic and Marine Oilspill Program (AMOP), Environment Canada, Ottawa, Ont., pp. 823-839, 1997.

6. McCourt, J., Buist, I., Mullin, J., Pratte, B., and Jamieson, W., Continued Development of a Test for Fire Booms in Waves and Flames, Proceedings of the Twenty-First Arctic and Marine Oilspill Program (AMOP), Environment Canada, Ottawa, Ont., pp. 505-528, 1998.

PROPANE BURN TESTING AT OHMSETT

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PROPANE BUBBLER SYSTEM

TEST SETUP

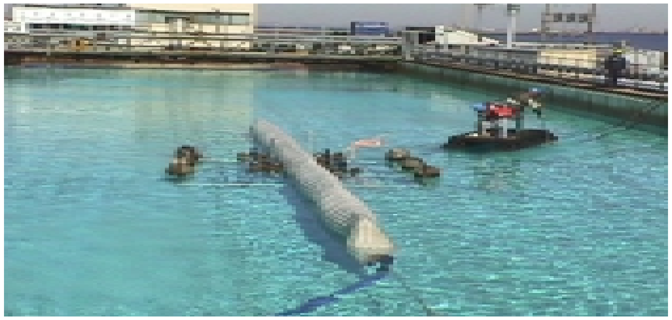
FLOATATION DEVICES

PROPANE TANKS

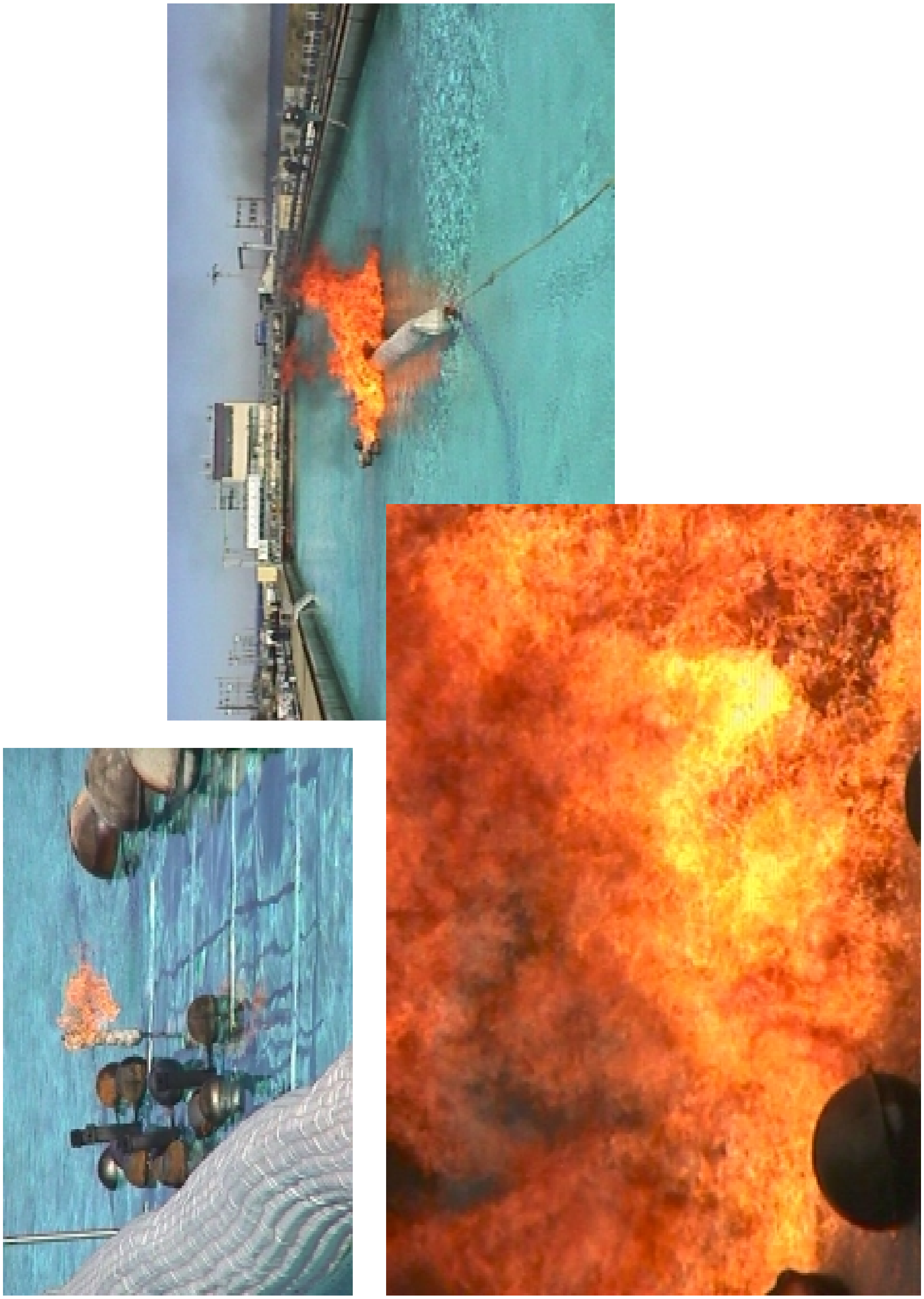
SETUP OF PROPANE INSTRUMENTATION

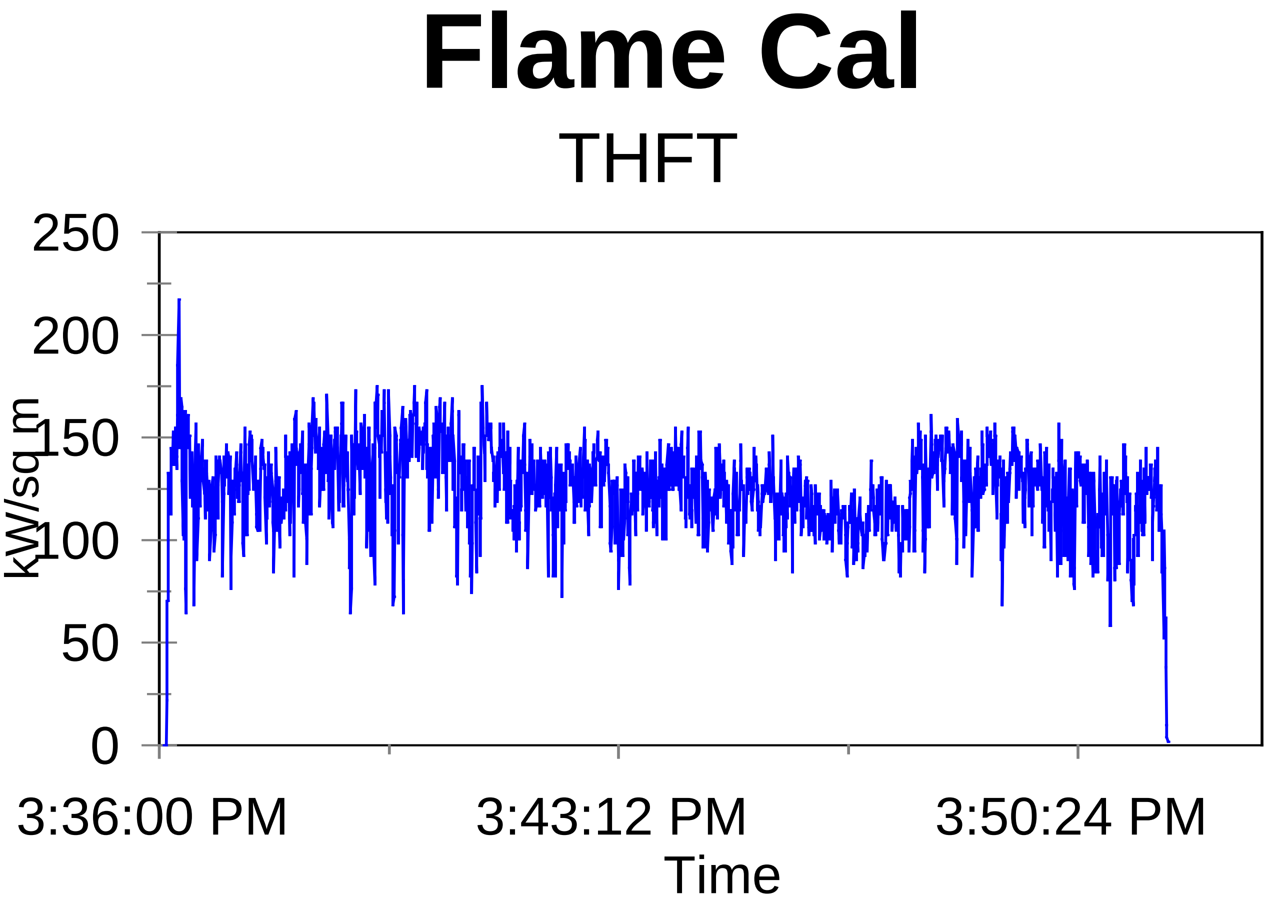
OHMSETT TEST BASIN

PREPARATION OF FIRE BLANKET



BURN IGNITION

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Post Burn

PREPAREDNESS FOR *IN SITU* BURNING OPERATIONS: AN ALASKAN PERSPECTIVE

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SUMMARY

Response organizations and contingency plan holders have spent millions of dollars in the last 10 years preparing for the use of *in situ* burning for spill response. Efforts have included research and development, extensive training, and the acquisition of fire-resistant booms and ignition systems. Unfortunately, despite this work, the probability that responders will actually be able to use *in situ* burning on a spill remains very small. The reasons include the public perception that burning is bad, a regulatory bias against *in situ* burning, and a general lack of comfort on the part of decision makers. Response organizations and contingency plan holders should not be expected to maintain an *in situ* burn capability if the chances of using it are extremely low and if they do not get credit for the capability in their contingency plans. This paper discusses the hurdles that need to be overcome to make *in situ* burning truly a primary response option.

HISTORICAL PERSPECTIVE

Alaska Clean Seas[1] and S.L. Ross[2] provide summaries of documented cases in which *in situ* burning has been used on actual spills. Since 1958 there have been only 21 such cases. These burns occurred in North America and in Europe and do not include events involving accidental ignition (i.e., tankers, blowouts, or production facilities). It is important to note that 10 of the 21 burns occurred in ice conditions where mechanical containment and recovery operations were hampered.

The number of documented cases of *in situ* burning is considered conservative. In the former Soviet Union, *in situ* burning has been, and continues to be, used as a preferred response technique. This preference appears to be driven by remoteness considerations, prevalence of ice conditions, lack of logistical infrastructure to mount a mechanical response, and the relative low cost of *in situ* burning compared to mechanical options[3].

Kucklick and Aurand[4] reviewed marine *in situ* burning opportunities in the United States between 1973 and 1991. They collected information on marine spills of 1,000 barrels or larger in the coastal and offshore waters of the United States (excluding Alaska). Each incident was examined against specific criteria to determine whether or not a spill could have been a candidate for *in situ* burning.

Criteria included an API gravity of less than 45, wind speeds of less than 19 kn, and a distance of at least 4.8 km (3 mi) from a sensitive receptor. Their review showed that on average there were two crude oil and two refined oil spills in the United States each year on which *in situ* burning might have been considered for use. Over the period reviewed, 45% of the crude oil spills and 25% of refined oil spills greater than 1,000 barrels were potential candidates for burning. When the criteria were modified (i.e., the distance from a receptor was decreased from 4.8 km [3 mi] to 0.4 km [0.25 mi]), the number of oil spills on which burning could have been considered nearly doubled. It should be noted that 99% of the spills in the United States between 1973 and 1991 were less than 1,000 barrels. Kucklick and Aurand used a l,000 barrel criterion because of data gaps on spills of lesser volumes. The authors note that the number of spills that were identified as candidates for *in situ* burning is probably low.

In the State of Alaska, *in situ* burning has been used as a response technique only twice since 1989. A test burn was conducted on the *Exxon Valdez* oil spill[5]; and in 1992, turbine fuel from a tank truck rollover in a mountain pass was successfully ignited. For Alaskan North Slope operations from 1989 to 1997, there have been 306 crude oil spills and 435 refined product spills, for a total of 741 spills. None of these spills was greater than 1,000 barrels.

Generally, it can be concluded that *in situ* burning has not been widely used as a spill response technique. Instances of use tend to involve spills in ice conditions where mechanical containment and recovery operations have been hampered or are ineffective.

REQUIRED CONDITIONS FOR BURNING

A number of physical limitations restrict the feasibility of *in situ* burning. These include wind speed, wave height, thickness of the oil, oil type, degree of weathering, and oil emulsification. The following are general rules of thumb for conducting *in situ* burning:

- Winds less than 20 kt (37 km/hr or 23 mi/hr).
- For on-water spills, waves of less than 62 cm to 92 cm (2 ft to 3 ft).
- A minimum thickness of 2 mm to 3 mm (0.08 in to 0.12 in) for fresh crude oil and thicker for diesel or weathered crude.
- For most crude oils, less than 30% evaporative loss.
- For oil-in-water emulsions, a water content of less than 25%.

In situ burning must be conducted in a defined window of opportunity--a fact clearly demonstrated during the *Exxon Valdez* spill in 1989[5].

PUBLIC PERCEPTION

Over the last 10 years, industry and government have attempted to rigorously characterize the health and environmental impacts of *in situ* burning and to refine the operational methodologies and tools for burning[6,7]. This effort has included development of public education tools to simplify the discussion of a complex and often emotional topic. For example, in 1995, the Alaska Department of Environmental Conservation (ADEC) and Alaska Clean Seas (ACS) jointly produced a public education pamphlet and video on the advantages, disadvantages, and environmental trade-offs of *in situ* burning[8].

Despite this effort, many public interest groups remain skeptical. In response to the 1998 draft environmental impact statement for the proposed offshore development of Northstar in the Beaufort Sea[9], Greenpeace raised several concerns about the practicability of *in situ* burning operations and about air pollution generated from the burning of an oil spill[10].

On the other hand, the Cook Inlet Regional Citizens' Advisory Council (Cook Inlet RCAC) has been a strong proponent of *in situ* burning as a primary spill response technique in Cook Inlet during the winter months. Upper Cook Inlet is typically covered with broken ice from mid-November to mid-April. The Cook Inlet RCAC recognizes the limited applicability of mechanical containment and recovery operations in broken ice conditions[11].

ACCEPTANCE OF *IN SITU* BURNING BY FACILITY MANAGERS

In a spill event involving an oil terminal, exploration well, pipeline, production facility or refinery, the Incident Commander position will most likely be filled by the facility manager. In general, facility managers tend to be reluctant to endorse *in situ* burning as a spill response tool[12]. In the course of normal duties, facility managers are responsible for the safety of their staff and facility. In any petroleum industry activity, great efforts are taken to minimize the risk of fire or explosion. There are numerous reminders of the consequences of unwanted fires in the petroleum industry.

Some justification may exist for this bias against *in situ* burning among facility managers. As an example, the methodology commonly described for extinguishing a burn on water is to speed up the tow and cause boom failure, allowing the oil to spread into a thin layer that will no longer support combustion. No successful use of this technique has been documented. Conversely, a crude oil burn was successfully conducted immediately adjacent to an aboveground portion of the trans-Alaska pipeline in 1978. This burn had no impact on operations or the integrity of the pipeline.

RESPONDER PREPAREDNESS

ACS is considered one of the leaders in the field of *in situ* burning. Since the early 1980s, ACS has conducted *in situ* burning research and development. ACS has funded and conducted a variety of projects including the NOBE (Newfoundland Offshore Burn Experiment) burn, the use of the heli-torch as an ignition device, and the burning of highly emulsified crude oils[13,14]. The value of the inventory of *in situ* burning equipment maintained by ACS exceeds $4.4 million--primarily in fire-resistant boom and aerial ignition systems. In addition, ACS maintains an active training program relating to *in situ* burning.

Both Cook Inlet Spill Prevention and Response, Inc. (CISPRI) and the Ship Escort/Response Vessel System (SERVS), the two other major Alaskan oil spill response organizations, also have been active participants in *in situ* burning research and development, and maintain significant burning capabilities. This includes fire-resistant boom and ignition systems, regular training, and pre-identified strategies for conducting burns. Interestingly, to maintain proficiency in heli-torch operations, CISPRI has worked with the local officials who use heli-torches in the control of forest fires.

THE REGULATORY ENVIRONMENT

According to the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) of the United States, the federal on-scene coordinator must obtain approval from the regional response team (RRT) for the use of *in situ* burning. Under the NCP, RRTs are required to address, as appropriate, such use through pre-authorization plans and agreements among the federal and state agencies. The Alaska Regional Response Team (ARRT) developed the *In Situ* Burning Guidelines for Alaska[15] in 1994. The guidelines state that burning will be considered as a possible response option only when mechanical containment and recovery response methods are incapable of controlling the spill. Additionally, in response to potential public health concerns, the ARRT established a safe downwind distance of 9.6 km (6 mi) from human populations as the primary decision criterion for conducting burning operations. This distance was based on modeling of the distance downwind at which atmospheric conditions will disperse particulate emissions of PM10 from an *in situ* burn to a concentration below 150 micrograms per cubic meter ($\mu g/m^3$). The ARRT adopted the U.S. Environmental Protection Agency's (EPA) 24-hour PM10 standard (150 $\mu g/m^3$). Based on guidance provided by the National Response Team (NRT), the averaging time was reduced from 24 hours to a one-hour average exposure limit.

The ARRT guidelines are presently under revision. According to the latest draft[16], federal and state on-scene coordinators will still consider burning only when mechanical containment and recovery are infeasible or incapable of controlling the oil spill. Based on the EPA's recently established particulate matter standard for PM2.5, the draft ARRT guidelines state that the safe distance separating human populations from *in situ* burns is the downwind radius for the fire at which PM2.5 concentrations at the ground diminish to 65 $\mu g/m^3$ averaged over 1 hour. Based on modeling, this is estimated to be at the 4.8 km (3 mi) range.

State regulations also can hamper decisions to use *in situ* burning. For example, the State of Alaska Oil and Hazardous Substances Pollution Control Regulations (18 AAC 75.430 - 440) require contingency plan holders to demonstrate on paper the ability to "contain or control and cleanup within 72 hours that portion of the response planning standard that enters open water." In 18 AAC 75.445(g)(l), plan holders are required to meet established response planning standards using mechanical containment and recovery methods. The regulations state that the response planning standards are means by which the adequacy of an oil spill plan can be judged by the Alaska Department of Environmental Conservation and that these standards do not constitute cleanup standards that must be met by the plan holder. This subtle differentiation is not readily understood by the general public. Contingency plans in Alaska have established a false expectation that cleanup of worst-case discharges can be achieved in 72 hours using mechanical containment and recovery operations. This becomes particularly problematic in ice environments, where the efficiency of mechanical containment and recovery operations is dramatically reduced as ice concentrations increase. This bias for mechanical containment and recovery is reinforced in the ARRT *In Situ* Burning Guidelines for Alaska[15].

THE CASE FOR *IN SITU* BURNING

As described above, *in situ* burning has not been used extensively as a response tool in the United States. Based on a skeptical public attitude, a regulatory bias for mechanical response, and the reticence of oil industry facility managers to allow burning in and around their facilities, one must question the utility of maintaining an *in situ* burning capability. Oil spill response cooperatives and industry have no incentive to continue to fund *in situ* burning research or maintain preparedness when there is little likelihood that the use of burning will be approved. We must not forget that the purchase and maintenance of spill response equipment and capability are costly. While this expense can be seen as a cost of doing business, great pressure exists in the oil industry to minimize expenses that cut into the bottom line--especially during times, like now, of low oil prices.

The arguments in favor of burning spilled oil are familiar to us all and are quite compelling mechanical removal is often limited; burning can prevent the spread of oil to shore, where most damage is done; burning eliminates many of the toxic volatiles that evaporate from an oil slick; burning protects wildlife from the physical effects of oiling; the human health risks are manageable and are related mainly to soot, and much of the spilled oil was originally destined to be turned into carbon dioxide anyway.

The fact that regional response teams have been tasked with developing guidelines for the use of burning indicates that some policymakers understand its value as a response tool. Why is it, then, that local RRTs and states make approval to burn an actual spill contingent on demonstrating that the use of mechanical techniques is impossible? We also know that to be effective, burning must start as soon as possible after the spill when the oil is most easily ignitable and before the oil begins to spread. In Alaska, response can be hampered by great distances, severe weather, lack of logistical infrastructure, and the presence of ice for several months of the year.

What is apparent is that many fail to recognize that in some cases, burning may be the only viable response option left to responders. Recently, the Alaska Department of Environmental Conservation, in a review of industry spill response capability in broken ice, suggested that the oil industry on the North Slope should acquire millions of dollars worth of barges and skimming equipment in an effort to marginally increase the ability to mechanically remove oil in broken ice[17]. This position is probably understandable, given the regulatory bias against burning, but does it make sense for the environment--and also for the industry--when the period of concern on the North Slope lasts for only a few weeks?

Under many conditions, particularly broken ice on water, *in situ* burning is the safest and most effective means to respond to a spill. In fact, one can easily argue that for such conditions, burning is the best available technology since it will potentially remove from the water far more oil than mechanical containment and recovery. Until regulators, facility operators, and the public are made to understand these facts, it is hard for spill response planners to recommend expenditures on equipment and training for a response technique that never will be used.

RECOMMENDED ACTIONS

- At the national level, there needs to be recognition of the potentially valuable role that *in situ* burning can play in spill response. For vessel response plans, federal regulations (33 CFR 154 and 155) call for an increase in the amount of mechanical recovery equipment that is required to be ensured, by contract or other approved means, in 1998 and 2003. Prior to implementing the so-called "cap" increases, the U.S. Coast Guard is required to conduct a review to determine if any proposed increases are practicable. The Coast Guard is considering including mandatory dispersant requirements in the 1998 scheduled cap increase. For those areas of the United States where dispersant may not be practicable on a year-round basis, a similar initiative should be considered for *in situ* burning.

- The Alaska state government needs to recognize that ice conditions are a fact of life over most of Alaska for several months of the year. State oil spill regulations were designed as a reaction to a batch release of oil in Prince William Sound (*Exxon Valdez*), where ice does not form in winter. They do not adequately address the conditions that exist throughout the rest of the state, particularly in the Beaufort Sea. The regulations should be revised to reflect the reality of response in ice-infested waters.

- Industry must educate and demonstrate to facility managers that *in situ* burning can be conducted safely in close proximity to their facilities.

- Responders, both in industry and the regulatory community, must continue to educate the public on the importance of *in situ* burning and its net environmental benefit.

REFERENCES

1. Alaska Clean Seas. Proposed plan for 1992 full scale *in situ* burn test, Beaufort Sea, Alaska. Application to U.S. Environmental Protection Agency (December 1991).

2. S.L. Ross Environmental Research Ltd. A review of *in situ* burning as a response for spills of Alaska North Slope crude oil in Prince William Sound. For: Prince William Sound Regional Citizens Advisory Council (May 1997).

3. Larsen, Phil. Personal communication. (During the 1995-96 response to the Komi pipeline oil spill in Russia, Mr. Larsen was employed by Hartec Management Consultants as the Deputy Project Manager.) (October 1998).

4. Kucklick, J.H. and Aurand, D. Historical dispersant and *in situ* burning opportunities in the United States. In: *Proceedings of the 1997 Oil Spill Conference*, April 7-l0, 1997, Fort Lauderdale, Florida (1997).

5. Allen, A.A. Controlled burning of crude oil on water following the grounding of the *Exxon Valdez*. In: *Proceedings of the 1991 International Oil Spill Conference*, March 47, 1991, San Diego, California (1991).

6. Buist, I.A., Ross, S.L., Trudel, B.K., Taylor, E., Campbell, T.G., Westphal, P.A., Myers, M.R., Ronzio, G.S., Allen, A.A., and Nordvik, A.B. The science, technology, and effects of oil spills at sea. Marine Spill Response Corporation, Washington, D.C. MSRC Technical Report Series 94-013 (1994).

7. Fingas, M., Ackerman, F., Li, K., Lambert, P., Wang, Z., Bissonnette, M., Campagna, P., Boileau, P., Laroche, N., Jokuty, P., Nelson, R., Turpin, R., Trespalacios, M., Halley, G., Belanger, J., Pare, J., Vanderkooy, N., Tennyson, E., Aurand, D., and Hiltabrand, R. The Newfoundland Offshore Burn Experiment: NOBE preliminary results of emissions measurement. In: *Proceedings of the Seventeenth Arctic and Marine Oil Spill Program (AMOP) Technical Seminar*. June 8-10, 1994, Vancouver, British Columbia. pp. 1099-1164 (1994).

8. Alaska Clean Seas and Alaska Department of Environmental Conservation. *In situ* burning: a valuable tool for oil spill response. Prudhoe Bay, Alaska (April 1995).

9. U.S. Army Engineer District, Alaska. draft environmental impact statement, Beaufort Sea oil and gas development/Northstar Project. Anchorage, AK (June 1998).

10. Greenpeace. Greenpeace comments to Northstar draft environmental impact statement. Letter dated August 31, 1998, to US. Army Corps of Engineers (1998).

11. Saupe, S.M. Summary of Cook Inlet RCAC correspondence/concerns regarding *in situ* burning guidelines. Letter dated November 20, 1997, from Cook Inlet RCAC to Alaska Regional Response Team (1997).

12. Skitmore, M., Project Manager, Northstar Development Project. Personal communication (October 1998). BP Exploration (Alaska) Inc.

13. Guenetter, C., Sveum, P., Buist, I., Aunaas, T., and Godal, L. *In situ* burning of water in oil emulsions. Sintef Applied Chemistry. Report STF2 1 A94053 (1994).

14. Buist, I.A., Glover, N., McKenzie, B., and Ranger, R. *In situ* burning of Alaska North Slope emulsions. In: *Proceedings of the 1995 International Oil Spill Conference*, February 27 - March 2, 1995, Long Beach, California (1995).

15. Alaska Regional Response Team. ARRT *in situ* burning guidelines for Alaska. In: *Unified Plan, Appendix II, Annex F* (1994).

16. Alaska Regional Response Team. ARRT *in situ* burning guidelines for Alaska. Revision 1. In: *Unified Plan, Appendix II, Annex F* (April 29, 1998).

17. Alaska Department of Environmental Conservation. Preliminary analysis of oil spill response capability in broken ice to support request for additional information for Northstar oil spill contingency plan. Anchorage, AK (August 5, 1998).

IN SITU BURNING OF OIL SPILLS:
A HISTORICAL PERSPECTIVE

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SUMMARY

The history of *in situ* burning is reviewed and perspectives on the key developments are given. The development of knowledge and techniques are noted and documented.

INTRODUCTION

In situ burning of oil spills has been tried over the past thirty years but has only recently been accepted as an oil spill cleanup option in some countries. The lack of acceptance of burning as a cleanup option is largely because of the lack of understanding of the combustion products and the principles governing the combustibility of oil-on-water. There remain several barriers to the full acceptance of burning, especially concern over emissions, but also the ability to retain oil slicks that are thick enough to burn.

This paper reviews the history and the state-of-the-art in burning to shed light on what is known and what remains to be researched. The history of burning is full of reversals, re-directions and re-inventions. Often a concept for ignition or containment reappears on the market or on a research list. Unfortunately, the progress has not been linear over the years and often efforts have been wasted on concepts or theories that yielded no benefit to the practical application of burning. The main cause of this is the interdisciplinary nature of oil spills. Researchers and engineers often are unaware of findings and concepts in each others fields. The practical approaches usually win out for funding, often at the detriment of advancement in the field. This paper will focus on the advancements and the progress made through the years and not the difficulties encountered on the way. Table 1 highlights some of the *in situ* burns and experiments over the past 30 thirty years.

PHILOSOPHY AND USE OF BURNING

Outside of Arctic regions, deliberate burning has not been used to a large extent. Several reviews contain histories of deliberate and accidental burns[1,2]. Often accidental burns were viewed as being detrimental to the situation and efforts to put out the burn were paramount to mounting other measures. Needless to say, a large release of oil from a stricken tanker would be motivation to stop a fire; however, such a threat was not always imminent. The current instinct is to put out the fire irrespective of the situation. Underlying this action, appears to be the view that burning is bad and results in negative effects on the situation and on the environment.

The acceptance and use of burning in a given country often depended on the success (or failure) of initial attempts to use the technique. The first recorded burn was in Northern Canada in 1958, where a log boom was used to successfully contain oil for *in situ* burning on the Mackenzie River. After this, many burns were conducted in Canada, most often without any form of documentation. Similarly, several successful burns in Sweden and Finland resulted in the use of burning on many occasions in those and surrounding countries. In Britain, extensive efforts to ignite the *Torrey Canyon* spill and the vessel itself resulted in mixed results. Consequently, burning has not been tried again in Britain until recently.

In recent years, the understanding of *in situ* burning has matured to the point where it will be accepted in several jurisdictions[3-5]. Burning is now an “approved” technique requiring authorities permission in most western countries. Despite, the newly-gained acceptance, there a no to few actual uses of *in situ* burning on open waters. It should be noted that *in situ* burning still has wide application on spills on land and on small waterbodies. *In situ* burning is used extensively in the petroleum-producing regions of Canada and the United States to deal with oil spills.

WHAT WILL BURN

In earlier years, theories varied as to the burnability of oils[6,7]. Some of the early papers suggested that some oils would not burn *in situ*. In fact, most if not all oils will burn on water or land if in sufficiently thick slicks. The "prime rule" of *in situ* burning is that oils will ignite if they are at least 2 mm to 3 mm thick. They will continue to burn down to slicks about 1 mm to 2 mm thick. The reason that these thicknesses are required is heat transfer. Sufficient heat is required to vaporize material for continued combustion. For very thin slicks, most of the heat is lost to the water and combustion is not sustained.

The effect of weathering on oil combustion is to increase the difficulty with which the material is ignited. Weathered oil requires a longer ignition time and somewhat higher ignition temperature. This is not a problem for most ignition devices because they generate sufficient temperature and have sufficient burning time to ignite most oils.

The effect of water content on oil ignition is similar to that of weathering. It is known that oil that is completely emulsified with water cannot be ignited. Oil containing some emulsion can be ignited and burned. The successful test burn of the *Exxon Valdez* oil had some emulsion present (probably less than 20%) and this did not affect either the ignitibility or the efficiency[8]. It is suspected that fire breaks down the water-in-oil emulsion, thus water content may not be a problem given that the fire can actually be started. At what point an emulsion can be ignited is not known. One test suggested that a heavier crude would not burn with about 10% water, another burned with as much as 50% and still another burned with about 70% water. Extensive studies on emulsions have shown that there are different categories and the results above may only relate to the stability of the emulsion[9]. There still remains extensive work to solve this problem.

Only limited work has been done on burning oil on shorelines. Because sub-strata are generally wet, minimum thicknesses are thought to be similar to those for on water--2 mm to 3 mm. Oil is sometimes deposited in layers much thinner than this. Burning may cause the part of the oil to penetrate further into the sediments. Where shorelines are close to human settlements and other amenities, burning would not be considered.

EMISSIONS FROM OIL SPILL BURNING

The concern over atmospheric emissions remains the biggest barrier to the widespread use of burning. Unfortunately, burning of all kinds, is in today's times, a questionable process because of concern over combustion by-products. Analysis is still difficult, although technology does permit analysis of key compounds and comparison to ambient levels of pollution.

Early papers on the topic did not report on extensive experiments, but focused either on simple measurements or predictions of the types of emissions that could be encountered. Some papers focused only on sulphur dioxide, others on PAHs. Only recent studies have explored hundreds of compounds to delineate the concerns with emissions. The following paragraphs summarize the current state-of-knowledge in the field[10-12].

All burns, especially those of diesel fuel produced an abundance of particulate matter. The concentrations of particulates from diesel at the same distances were approximately 4 times that for similar-sized crude oil burns. Concentrations of particulate matter with diameters of 10 µm or less (PM10) were sometimes about 0.7 of the total particulate concentration (TSP), as would be expected, but sometimes were the same as the TSP. The same is true of the PM2.5 concentrations.

Crude oil burns result in polycyclic aromatic hydrocarbons (PAH) downwind of the fire, but the concentration on the particulate matter is often an order-of-magnitude less the concentration in the starting oil. Diesel fuel contains low levels of PAHs with smaller molecular size, but results in more PAHs of larger molecular sizes. Larger PAHs are either created or concentrated by the fire. Larger PAHs, some of which are not even detectable in the diesel fuel, are found both in the soot and in the residue. The concentrations of these larger PAHs are however low and often just above detection limits. Overall, more PAHs are destroyed by the fires than are created.

One-hundred and forty-eight volatile organic compounds (VOC) were measured from samples taken in recent studies. The concentrations of VOCs are about the same in a crude or diesel burn. Concentrations appear to be under human health limits even at the closest monitoring station (about 30 m). VOC concentrations are about three times higher when the oil is not burning and is just evaporating. Unfortunately, this is difficult to measure at all burns.

Particulates precipitated downwind and oil residue were analyzed for dioxins and dibenzofurans, very toxic substances often produced by the burning of organic chlorine-containing compounds. The levels of these toxic compounds were at background levels indicating no production by either crude or diesel fires.

Oil burns produce low amounts of the small aldehydes (e.g., formaldehyde, acetaldehyde) and ketones (e.g., acetone). These would not be a health concern even close to the source fire. Carbonyls from crude oil fires are at very low concentrations.

Carbon dioxide is the end result of combustion and is found in increased concentrations around a burn. Normal atmospheric levels are about 300 ppm and levels near a burn can be around 500 ppm. There is no human danger in this level. The three-dimensional distributions of carbon dioxide around a burn have been measured. Concentrations of carbon dioxide are highest at the 1 m level and fall to background levels at the 4 m level. Concentrations at ground level are as high as 10 times that of the plume. Distribution along the ground is broader than for particulates.

Carbon monoxide levels are usually at or below the lowest detection levels of the instruments and thus do not pose any hazard to humans. The gas only has been measured when the burn appears to be inefficient, such as when water is sprayed into the fire. Carbon monoxide appears to be distributed in the same way as carbon dioxide. Sulphur dioxide, per se, is usually not detected at significant levels or sometimes not even at measurable levels. Sulphuric acid, or sulphur dioxide that has reacted with water, is detected at fires and levels, although not of concern, appear to correspond to the sulphur contents of the oil. Attempts were made to measure oxides of nitrogen and other fixed gases. None were measured in about 10 experiments.

A concern about burning crude oil lies with any "hidden" compounds that might be produced. One study was conducted several years ago in which soot and residue samples were extracted and "totally" analyzed in various ways. The study was not conclusive; however, no compounds of the several hundred identified were of serious environmental concern. The soot analysis revealed that the bulk of the material was carbon and that all other detectable compounds were present on this carbon matrix in abundances of parts-per-million or less. The most frequent compounds identified were aldehydes, ketones, esters, acetates and acids. These are formed by incomplete oxygenation of the oil. Similar analysis of the residue shows that the same minority compounds are present at about the same levels. The bulk of the residue is unburned oil.

The quantity of soot produced by *in situ* oil fires is unknown. No measurement techniques exist because the emissions from fires cover a large area. Estimates of soot production vary from 0.2 % to 3% of the starting oil volume, however some older techniques reported numbers as high as 16%. These estimates are complicated by the fact that particulates precipitate from the smoke plume. This appears to occur at an exponential rate from the fire outwards. Some researchers have tried to estimate soot production by performing a carbon balance. They measure the soot quantity and the carbon dioxide concentration at the same point in the smoke plume. The soot production is estimated by taking the percentage of soot versus the total amount of carbon in both the soot and carbon dioxide. This technique results in high estimates of soot production and is flawed because the soot is largely confined to the smoke plume but the carbon dioxide is emitted over a very wide sector. Further work on quantity of soot production is required.

IGNITION

Much of the earlier work focused on the ignition of slicks[13,14]. The thinking was that proper ignition was the key to successful burning of oil on water. Studies conducted in the last ten years have shown that ignition is relatively unimportant. Research has shown that slick thickness is the major factor and ignition is only important under certain circumstances. Heavy oils require longer heating times and a hotter flame to ignite compared to lighter oils. Many ignition sources can supply sufficient heat for sufficient length of time.

Several igniters have been developed. A simple device consisting of juice cans and propellant was developed by Dome petroleum and was known as the "Dome" igniter. Environment Canada and the Canadian military developed a device with a sophisticated time fuse. This device was commercialized under the name "Pyroid" but did not continue in production. Some of these devices are used from time to time for experimental spills. Work also was conducted on developing a laser ignition device, although a working unit was not completed. The state-of-the-art in ignition technology is a device called the "heli-torch". It is a helicopter-slung device which distributes packets of burning, gelled fuel.

Actual burns at some incidents and experiments have been ignited using much less sophisticated means. The *Edgar Jordain* spill was lit using a roll of diesel-soaked toilet paper. The east coast oil burns were lit using oil-soaked sorbent. The test burn at the *Exxon Valdez* spill was ignited using a lunch "baggie" filled with gelled gasoline. This illustrates the ease and lack of sophistication that is required to ignite oil slicks.

EFFICIENCY AND BURNING RATES

In early years, it was presumed that burn efficiency was somehow related to oil type. It is now known that burning efficiency is simply a matter of initial thickness and of encounter. Efficiency is largely a function of oil thickness. Oil thicker than about 2 mm to 3 mm can be ignited and this will burn down to about 1 mm to 2 mm. If we ignite a slick at, lets say, 2 mm and this burns down to 1 mm, our efficiency can be at most 50%. However if we ignite a pool of oil 20 mm thick and this burns down to 1 mm, our efficiency of removal is about 95%. Current research has shown that other factors such as oil type and water content only marginally affect these values.

The residue from oil spill burning is largely unburned oil with some lighter or more volatile products removed. It is adhesive and because of this, somewhat easy to recover with manual techniques. Recent concern has been raised over the fact that these may sink, but this is only speculation and has only occurred on two spills.

Most oil pools burn at a rate of about 3 mm/min to 4 mm/min. This means that the depth of oil is reduced by 3 mm/min to 4 mm/min. Several tests have shown that this does not vary significantly with oil type, weathering and water content. As a rule of thumb, one can burn about 5000 litres per-square-metre per-day (or about 100 gallons-per-square-foot per-day).

BURNING TECHNIQUES

Containment is usually required to concentrate oil slicks so that they are of sufficient thickness to ignite and burn efficiently. Lightweight and fire-resistant booms now exist which make burning very feasible. The trial burn conducted at the *Exxon Valdez* site illustrates how oil spills can be burned without threatening the spill source. Two fishing vessels towed a fire-resistant boom using long tow lines. The boom was towed slowly through the slick until the boom-holding capacity was reached. The oil-filled boom then was towed away from the main slick and the oil ignited. Fire could not spread to the main slick because of the distance.

Burning *in situ* without the benefit of containment boom can be done only if sufficient thickness (2 mm to 3 mm) exists to ignite the oil. For most crude oils this only occurs for a few hours after the spill event. Oil on the open sea rapidly spreads to equilibrium thicknesses. For light crude oils this is about 0.01 mm to 0.1 mm, for heavy crudes and heavy oils this is about 0.05 mm to about 0.5 mm. These are far too thin to ignite.

Log booms were first used to contain oil for burning and this was successful. In the early 1970s Environment Canada initiated several projects to develop fire-resistant containment techniques, water spray and air jet were examined but abandoned because of the impracticality of this approach. Several series of stainless steel booms were built and also different versions of ceramic booms. Alaskan workers and 3M pioneered the development of a flexible fire-resistant boom and this product continues until today. Dome petroleum pursued one of the stainless steel booms and this product has been recently been re-engineered into a smaller product.

Lately much work has been conducted on fire-resistant booms. This has been highlighted by two series of tests of these at Mobile, Alabama to test the fire resistance and further testing of the same booms at OHMSETT (the National Oil Spill Response Test Facility in Leonardo, New Jersey) for the usual containment parameters. These tests have highlighted several insights about fire-resistant booms. First, a simple fire-resistant blanket over the top of a standard boom will not function well for the purpose. Second, heavy metal booms may be impractical in operational situations, despite their outstanding ability to withstand fire. Third, water-cooled booms, although functional in test situations, may not be practical in open burn situations. Obviously, more development is still needed.

CONCLUDING REMARKS

Progress has been immense in the ability to apply *in situ* burning. Better information transfer is still needed. It has been noted that literature in the field and general scientific literature often is not used. On the positive side, more spill workers are accepting burning as a technique and are receptive to information on the technique.

REFERENCES

1. Thompson, C.H., G.W. Dawson and J.L. Goodier, *Combustion: An Oil Spill Mitigation Tool*, DOE/EV-1830-1 (UC-11), United States Department of Energy, Washington, D.C., 554 p., November, 1979.

2. Buist, I.A., S.L. Ross, B.K. Trudel, E. Taylor, T.G. Campbell, P.A. Westphal, M.R. Myers, G.S. Ronzio, A.A. Allen, and A.B. Nordvik, The Science, Technology, and Effects of Controlled Burning of Oil at Sea, MSRC Report Series 94-013, 1994.

3. Addassi, Y.N., *In Situ* Burning Policy Development For California: A Consensus Approach to Policy and Decision-Making, in *Proceedings of the Twentieth Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 243-252, 1997.

4. Alyeska Pipeline Service Company, *Prince William Sound Tanker Oil Discharge Prevention and Contingency Plan, Part 3 SID #16, Burning as a Response Tool,* PWS-203-16, Anchorage, Alaska, 94 p., 1997.

5. ASTM Committee F-20 on Hazardous Substances and Oil Spill Response, *Standard Guide For In Situ Burning of Oil Spills on Water: Environmental and Operational Considerations*, Designation: F 1788-97, American Society For Testing and Materials, Philadelphia, Pennsylvania, pp. 1007-1012, 1997.

6. Twardus, E.M., *A Study to Evaluate the Combustibility and Other Physical and Chemical Properties of Aged Oils and Emulsions,* EE-5, Environment Canada, Ottawa, Ontario, 169 p, 1980.

7. Twardus, E.M. and T.A. Brzustowski, The Burning of Crude Oil Spilled on Water, *Archivium Combustionis,* Vol. 1, pp. 51-60, 1981.

8. Allen, A.A., Contained Controlled Burning of Spilled Oil During the Exxon Valdez Oil Spill, in *Proceedings of the Thirteenth Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 305-313, 1990.

9. Fingas, M.F., B. Fieldhouse and J.V. Mullin, Studies of Water-in-Oil Emulsions: Stability and Oil Properties, in *Proceedings of the Twenty-First Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 1-25, 1998.

10. Lambert, P., F. Ackerman, M. Fingas, M. Goldthorp, B. Fieldhouse, R. Nelson, M. Punt, S. Whiticar, S. Schuetz, A. Dubois, M. Morganti, K. Robbin, R. Magan, R. Pierson, R.D. Turpin, P.R. Campagna, D. Mickunas, R. Nadeau, and R.A. Hiltabrand, Instrumentation and Techniques for Monitoring the Air Emissions During *In situ* Oil/Fuel Burning Operations, in *Proceedings of the Twenty-First Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 529-567, 1998.

11. Fingas, M.F., P. Lambert, F. Ackerman, B. Fieldhouse, R. Nelson, M. Goldthorp, M. Punt, S. Whiticar, P.R. Campagna, D. Mickunas, R.D. Turpin, R. Nadeau, S. Schuetz, M. Morganti, and R.A. Hiltabrand, Particulate and Carbon Dioxide Emissions from Diesel Fires: The Mobile 1997 Experiments, in *Proceedings of the Twenty-First Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 569-598, 1998.

12. Fingas, M.F., F. Ackerman, P. Lambert, K. Li, Z. Wang, J. Mullin, L. Hannon, D. Wang, A. Steenkammer, R. Hiltabrand, R.D. Turpin and P.R. Campagna, The Newfoundland Offshore Burn Experiment: Further Results of Emissions Measurement, in *Proceedings of the Eighteenth Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 915-995, 1995.

13. Meikle, K.M., Incendiary Device For Oil Slick Ignition, in *Proceedings of the Fourth Annual Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 499-513, 1981.

14. Allen, A.A., Alaska Clean Seas Survey and Analysis of Air-Deployable Igniters, in *Proceedings of the Ninth Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 353-373, 1986.

Table 1. Historical Burns and Spill Studies

Year	**Location**	**Description**	**Events**	**Lessons**
1958	Canada	Mackenzie River, NWT	First recorded use of *in situ* burning, on river using log booms	*In situ* burning possible with use of containment
1967	Britain	*Torrey Canyon*	Cargo tanks difficult to ignite with military devices	There maybe limitations to burning
1969	Holland	series of experiments	Igniter KONTAX tested, many slicks burned	Burning at sea is possible
1970	Canada	*Arrow*	Limited success burning in confined pools	Confinement may be necessary for burning
1970	Sweden	*Othello/Katelysia*	Oil burned among ice and in pools	Can burn oil contained by ice
1970	Canada	Deception Bay	Oil burned among ice and in pools	Can burn in ice and in pools
1973	Canada	Rimouski - experiment	Several burns of various oils on mud flats	Demonstrated high removal rates possible, >75%
1975	Canada	Balaena Bay - experiment	Multiple slicks from under ice oil ignited	Demonstrated ease of burning oil on ice
1976	U.S.A.	*Argo Merchant*	Tried to ignite thin slicks at sea	Not able to burn thin slicks on open water
1976	Canada	Yellowknife - experiment	Parameters controlling burning not oil type alone	Parameters controlling burning not oil type alone
1978-82	Canada	series of experiments	Studied many parameters of burning	Found limitations to burning was thickness
1979	Mid-Atlantic	*Atlantic Empress/ Aegean Captain*	Uncontained oil burned at sea after accident	Uncontained slicks will burn at sea directly after spill
1979	Canada	*Imperial St. Clair*	Can readily burn fuels with ice	Can readily burn fuels amongst ice
1980	Canada	McKinley Bay - experiment	Several tests involving igniters, different thicknesses	Test of igniters, measured burn rates
1981	Canada	McKinley Bay - experiment	Tried to ignite emulsions	Noted difficulty in burning emulsions

Year	**Location**	**Description**	**Events**	**Lessons**
1983	Canada	*Edgar Jordain*	Vessel containing fuels and nearby fuel ignited	Practical effectiveness of burning amongst ice
1983	U.S.A.	Beaufort Sea - experiment	Oil burned in broken ice	Ability to burn in broken ice
1984	Canada	series of experiments	Tested the burning of uncontained slicks	Uncontained burning only possible in few conditions
1984-5	U.S.A.	Beaufort Sea - experiment	Burning with various ice coverages tested	Burning with various ice coverages possible
1984-6	U.S.A.	OHMSETT - experiments	Oil burned among ice but not with high water content	Ice concentration not important, Emulsions don't burn
1985	Canada	Offshore Atlantic - experiment	Oil among ice burned after physical experiment	Ease of burning amongst ice
1985	Canada	Esso - Calgary - experiments	Several slicks in ice leads burned	Ease of burning in leads
1986	Canada	Ottawa - experiments/analysis	Analyzed residue and soot from several burns	Analysis shows PAH's about same in oil and residue
1986	U.S.A.	Seattle and Deadhorse - experiment	Test of the heli-torch and other igniters	First demonstrations of heli-torch as practical
1986-91	U.S.A.	NIST - experiments	Many lab-scale experiments	Science of burning, rates, soot, heat transfer
1986-91	Canada	Ottawa - analysis on above	Analyzed residue and soot from several burns	Found PAH's and others - not major problem
1989	U.S.A.	*Exxon Valdez*	A test burn performed using a fire-proof boom	One burn demonstrated practicality and ease
1991	U.S.A.	First set of Mobile burns	Several test burns in newly-constructed pan	Several physical findings and first emission results
1992	U.S.A.	Second set of Mobile burns	Several test burns in pan	Several physical findings and emission results
1992	Canada	Several test burns in Calgary	Emissions measured and ferrocene tested	Showed smokeless burn possible

Year	**Location**	**Description**	**Events**	**Lessons**
1993	Canada	Newfoundland Offshore burn	Successful burn on full scale off shore	Hundreds of measurements, practicality demonstrated
1994	U.S.A.	Third set of Mobile burns	Large scale diesel burns to test sampler	Many measurements taken
1994	U.S.A.	North Slope burns	Large scale burn to measure smoke	Trajectory and deposition determined
1994	Norway	Series of Spitzbergen burns	Large scale burns of crude and emulsions	Large area of ignition results in burn of emulsions
1994	Norway	Series of Spitzbergen burns	Try of uncontained burn	Uncontained burn largely burned
1996	Britain	Burn test	First containment burn test in Britain	Demonstrated practicality of technique
1996	U.S.A.	Test burns in Alaska	Igniters and boom tested	Some measurements taken
1997	U.S.A.	Fourth set of Mobile burns	Small scale diesel burns to test booms	Emissions measured and booms tested
1997	U.S.A.	North Slope tank tests	Conducted several tests on waves/burning	Waves not strongly constraining on burning
1998	U.S.A.	Fifth set of Mobile burns	Small scale diesel burns to test booms	Emissions measured and booms tested

MONITORING OF *IN SITU* BURNING OPERATIONS

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SUMMARY

Monitoring *in situ* burning (ISB) operations requires prompt notification, rapid deployment to the monitoring sites, and prudence in collecting and interpreting the data against background readings and possible interferences. The National Oceanic and Atmospheric Administration (NOAA) and the U.S. Coast Guard (USCG) have developed a monitoring program, recently exercised in two test burns. The exercises provided valuable lessons, and indicated that the monitoring program is feasible.

INTRODUCTION

In situ burning of spilled oil may provide a rapid and efficient method for reducing the environmental damage of oil spills. *In situ* burning, however, emits copious amounts of black smoke. Particulates in the smoke raise concerns of possible impact of the smoke on downwind population centers . As guidelines for incorporating *in situ* burning into regional response plans were being developed around the country, the issue of monitoring *in situ* burning operations became more relevant. In the early 1990s, U.S. Coast Guard District 8 recognized the need to provide the Unified Command with real-time data on ground-level concentration trends of particulates during *in situ* burning operations. Accordingly, NOAA and the U.S. Coast Guard Strike Teams developed the Special Response Operations Monitoring Program (SROMP) to help the Unified Command with decision making during *in situ* burning and dispersant operations[1].

Several land burns and a series of test burns in Mobile, Alabama provided the opportunity to test the SROMP. Based on lessons learned, the SROMP was reviewed, modified, improved, and renamed. The Special Monitoring of Advanced Response Technologies (SMART), a cooperative effort now under way by the Coast Guard, NOAA, U.S. Environmental Protection Agency and the Centers for Disease Control and Prevention will provide a National guidelines for monitoring *in situ* burning and dispersants operations.

MONITORING PROCEDURES

Monitoring *in situ* burning operations presents several challenges:

- Short window of opportunity
- Rapid mobilization and deployment
- Meaningful data collection
- Data interpretation and recommendations

Short Window of Opportunity

In situ burning may have a limited temporal window of opportunity. On land, *in situ* burning may be conducted days, sometimes weeks after the oil has spilled[2], giving all involved enough time to prepare for the burn. On the open seas, *in situ* burning may be limited by dispersion and emulsification of the oil, and by wind and sea conditions. It is advantageous to conduct *in situ* burning as soon after the spill as possible. If monitoring is needed, prompt notification to the monitoring teams may give them enough time to prepare for the burn and deploy on time.

Mobilization and Deployment

Once notified, the monitoring teams should be able to mobilize and reach the monitoring sites quickly, and use whatever transportation is best suited to the task when on site. To achieve this, the teams must have the logistical capabilities to be on call 24 hours a day, and to mobilize and deploy, fully prepared, within a short time (a few hours at most). Under SROMP and SMART, the USCG Strike Teams are tasked with monitoring ISB, and have at their disposal aircrafts, boats, monitoring equipment, and other items needed for successful monitoring. Some states, such as Washington and Hawaii, rely on their own resources to conduct monitoring for *in situ* burning.

SMART recommends using three teams for the monitoring task. The teams constitute a Group under the Incident Command System (ICS), and have their own leader, the Monitoring Group Supervisor. After arriving on site, the Group Supervisor reports to the Operations section in the ICS, get briefed by the Burn Coordinator, and selects monitoring locations. Selection of monitoring location depends on where the smoke is anticipated to go and the presence of population centers. If the smoke trajectory is expected to go over population centers, the monitoring teams are deployed to these locations, choosing specific sites that are as free as possible from interfering factors (e.g., industrial activity) in order to provide objective feedback to the Unified Command. For example, if the teams are deployed to a town (Figure 1), one team deploys upwind in the path of the smoke plume, one deploys downwind, and the third deploys at the discretion of the Burn Coordinator.

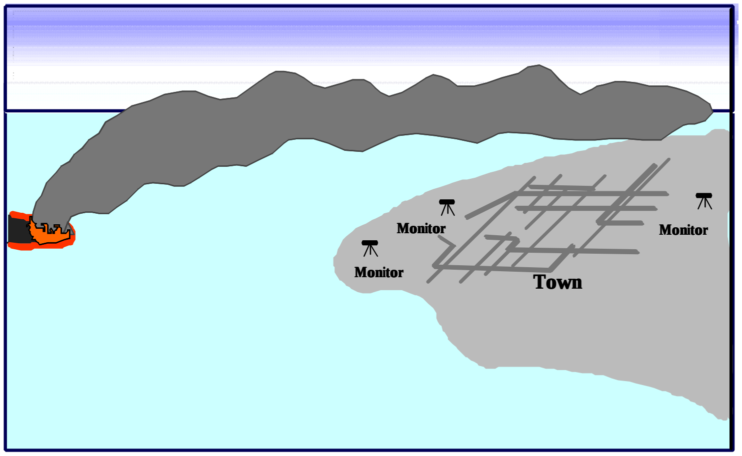

Figure 1. Possible monitoring locations (not to scale)

Data Collection

The monitoring teams are equipped with real-time particulate monitors (DataRam or similar) capable of sampling particulates 10 micrometers or smaller and presenting the data as micrograms per cubic meter of air (µg/m^3). This or similar instruments have been used in the past to monitor numerous burns[3,4]. The instruments provide instantaneous reading of particulate concentrations, as well as a time-weighted average (TWA) over the duration the instrument has been logging data. In addition, each team is equipped with a Global Positioning System (GPS), binoculars, radio, cellular phone, safety equipment, and the necessary recording forms.

Ideally, the monitoring teams are deployed before the burn starts, so that they can record the ambient concentration of particulates. After the burn starts, the teams keep on logging the data, both automatically in the datalogger of the instrument, and manually in a Recorder Log form. The manually-recorded data includes names, instrument number, date, time, location (general and coordinates from GPS), weather on site, and instantaneous and TWA readings every five minutes or less. Comments such as interferences from other factors, smoke direction, and any pertinent detail are recorded as well.

Experience suggests that, if the smoke plume is stable and high overhead, instrument readings will not exceed the ambient levels recorded before the burn. If, however, the plume is low and reaches ground level, such as with high wind conditions, instantaneous readings fluctuate greatly, from ambient concentrations up to momentary readings of several hundred µg/m^3, sometimes higher.

TWA readings are elevated as well, reflecting the trend of higher average particulate levels during that time. The teams pay close attention to the instrument and to the general environment. Higher and erratic instantaneous readings may suggest that particulate concentration from the burn is elevated, but also may suggest interferences from vessels, industry, or other particulate-generating sources. The teams pay special attention to the TWA. Consistently higher TWA readings may indicate an elevated particulate trend. The teams communicate this information to the Group Supervisor, who is on site with the three teams, and the Group Supervisor passes on this information to the Unified Command for consideration.

Data Interpretation and Recommendations

In the Unified Command, the data goes to the Planning section, and specifically to the Technical Advisors. In spills overseen by the USCG, this role is filled by the NOAA Scientific Support Coordinator (SSC). In general, the SSC may use guidance provided by the National Response Team (NRT) to interpret the data and formulate recommendations. The NRT recommends a conservative upper limit of 150 micrograms of PM10 per cubic meter of air, averaged over one hour[5]. Furthermore, the NRT emphasizes that this level of concern does not constitute a fine line between safe and unsafe conditions, but instead 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 the burn. 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 National Ambient Air Quality Standard (NAAQS).

When addressing particulate monitoring for *in situ* burning, the NRT emphasizes that concentration trends rather than individual readings should be used to determine whether to continue the burn or to consider terminating it. For SMART operations, the TWA generated by the particulate monitors should be used to ascertain the trend.

The NRT recommends that burning not take place if the air quality in the region already exceeds the NAAQS, and if burning the oil will add to exposure of the general population to particulates. The monitoring teams should report ambient readings to the Unified Command, especially if these readings approach or exceed the NAAQS.

MONITORING THE TEST BURNS IN MOBILE

A series of test burns near Mobile, Alabama, in September of 1997 and 1998 provided an opportunity to exercise the monitoring protocol. The goals of the exercises were to test the procedures of the SROMP and the SMART, and learn from field practice of the monitoring protocol.

The procedure was similar in both years: the monitoring teams assembled at one location, the instruments were set up and calibrated, and any setup problems, were addressed by the group. When ready, the teams deployed in small boats (since the burn was conducted on an island, using boats enabled the teams to monitor far enough downwind) and transited to the burn area. After arriving on location, the teams deployed downwind along the anticipated path of the smoke plume, and started collecting background readings which varied depending on wind direction and industrial activity; the burn site is near a coal terminal and the ship channel, both of which are sources for particulates. In addition, during calm, stable conditions of early morning, the background concentration of particulates was higher than later in the day.

After the oil was ignited the teams continued logging the data, both in the instruments and manually, recording interferences such as boats passing by and relevant information such as location of the boat relative to the smoke plume, distance from the burn area and locations (based on GPS readings). After the burn ended and the smoke dissipated, the monitoring continued for 15 minutes or so to collect post-burn ambient readings.

To maximize the training opportunity, the boats tried to stay underneath (on some occasions, inside) the smoke plume, so that monitoring personnel could experience recording elevated levels of particulates, comparing instantaneous readings to TWA readings, and communicating data to the Group Supervisor. In a real burn, however, SMART recommends that the teams remain at the location assigned to them, moving only to improve sampling capabilities. Chasing smoke is not the purpose of SMART.

The lessons learned from these burns were quite valuable. The most important lesson is that monitoring *in situ* burning operations by a mobile, flexible team is feasible. First, feedback provided to the Unified Command by on-site, real-time monitoring can enhance decision-making concerning the burn. Second, the instruments proved to be rugged and, in most cases, reliable. Third, manual recording of data may not capture all the momentary excursions of particulate concentration (Figure 2), but adequately follows the time-weighted average, which better conveys particulate concentration trends (Figure 3). Fourth, quality control of the protocol and the data is important, in order to have confidence in the output of the instrument. In addition to the usual steps (e.g., proper calibration, non-use of unfit instrument) it is important to note and record of environmental conditions and interferences that may affect the reading.

CONCLUSIONS

Monitoring *in situ* burning operations present several challenges. The short window of opportunity for *in situ* burning at sea necessitates rapid deployment of the monitoring teams. Once on site, the teams need to collect real-time particulate concentration trends, and convey them to the Unified Command. At the Unified Command the data should be evaluated and, if needed, proper recommendations made regarding the status of the burn. Several exercises and land burns showed that the monitoring protocol is feasible, and the protocol provided valuable lessons learned, among them the importance of quality controls, manual recording of the data, and accounting for possible effects of particulate-generating interfering factors.

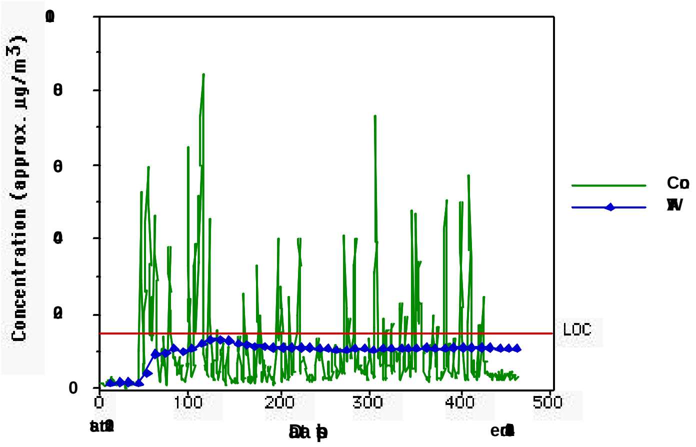

Figure 2. Particulate concentrations from the data logger output.

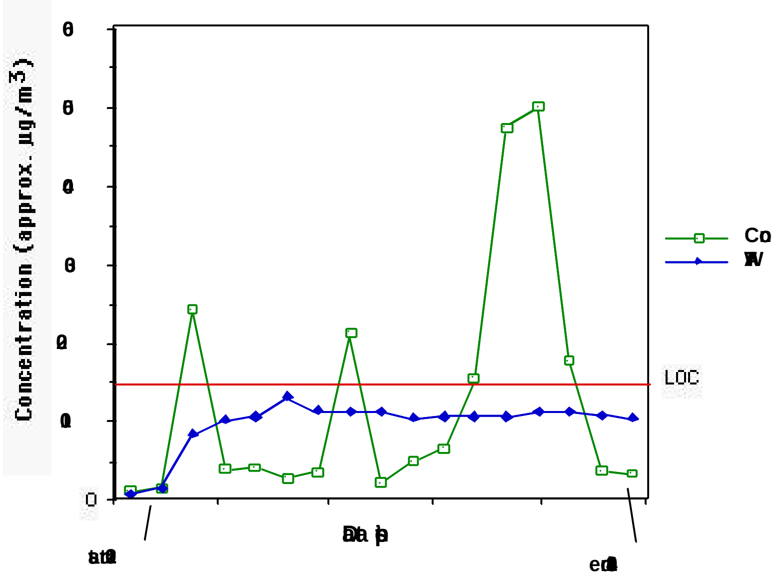

Figure 3. Particulate concentrations based on manually recorded data.

REFERENCES

1. NOAA Hazmat, USCG Gulf Strike Team. Special Response Operations Monitoring Program, SROMP. NOAA-GST Joint Project, Seattle WA (1994).

2. Eufemia, S. J. Brunswick Naval Air Station JP-5 Aviation Fuel Discharge *In situ* Burn of Fuel Remaining in Fresh Water Marsh April 608, 1993. In: Proceedings of *In situ* Burning of Oil Workshop. Nora H. Jason, Editor. January 26-28, 1994, Orlando, FL, National Institute of Standards and Technology, pp. 87-90 (1994).

3. Bissonnette, M.C., Fingas, M.F., Nelson, R.D., Beaudry, P. and Pare, J.R.J. Crude Oil Combustion at Sea: The Sampling of Released Products Using Remote Controlled Goats. In: Proceedings of the Seventeenth Arctic and Marine Oil Spill Program Technical Seminar, June 8-10, 1994, Environment Canada, Vancouver, British Columbia, pp. 1065-1081 (1994).

4. McGrattan, K. B., Walton, W. D. and Evans, D.D. Smoke Plume from *In Situ* Burning of Crude Oil. In: Proceeding of the International Oil Spill Conference, April 7-10, 1997, Ft. Lauderdale, FL, pp. 137-147 (1997).

5. National Response Team. Guidance on Burning Spilled Oil *In Situ*. Science and Technology Committee Report, Washington DC (1995).

SMOKE PLUME TRAJECTORY MODELING

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SUMMARY

A combination of numerical modeling and large scale experimentation has yielded a tremendous amount of information about the structure, trajectory and composition of smoke plumes from large crude oil fires. A numerical model, ALOFT (A Large Outdoor Fire plume Trajectory), has been developed at NIST to predict the downwind concentration of smoke and other combustion products. The model is based on the fundamental conservation equations that govern the introduction of hot gases and particulate matter from a large fire into the atmosphere. The model has been used to estimate distances from fires under of variety of meteorological and topographic conditions where ground level concentrations of smoke and combustion products fall below regulatory threshold levels.

BACKGROUND

Buoyant windblown plumes have been studied since the early 1960s. A summary of the early work together with a useful bibliography is given by Turner[1]. For summaries of more recent work see Turner[2] and Wilson[3]. Most of the models described in these works are integral models, where the profiles of physical quantities in cross-sectional planes perpendicular to the wind direction are assumed, together with simple laws relating entrainment into the plume to macroscopic features used to describe its evolution. A great many of the models in use for air quality assessment simply use Gaussian profiles of pollutant density. Of the available models, the ISCST3 (Industrial Short Complex, Short Term)[4], the CTDMPLUS (Complex Terrain Dispersion Model PLus algorithms for Unstable Situations)[5], the Offshore and Coastal Dispersion (OCD) model[6] or the CALPUFF model[7] could be used to estimate the dispersion of combustion products from *in situ* burning. The ISCST3 model is a popular Gaussian model designed to predict short-term (hours, days), short-range (1 km to 10 km) concentrations of pollutants from industrial sources. The related model CTDMPLUS considers more complex terrain. The OCD model was developed to assess the impact of offshore emissions on the air quality of coastal regions. It features added algorithms to account for atmospheric conditions unique to the coastal environment. The CALPUFF[7] model is not a Gaussian model; rather it tracks “puffs” of pollutants through a temporally and spatially changing atmosphere. The CALPUFF model still uses empirical plume rise formulae and simplified rules to track the pollutants over terrain features such as hills and mountains.

The potential shortcomings of these types of models are that they were designed for typical industrial sources, like smokestacks, that are much smaller in terms of energy output than an oil fire. The plume from an *in situ* burn of oil will rise higher into the atmosphere, and it is difficult to predict the rise based on empirical correlations. If the plume rise is not calculated correctly, substantial errors in downwind concentration can result. In the case of smokestack emissions, the plume does not rise appreciably high, reducing the uncertainty of the results. For this type of problem, the Gaussian models can be expected to give a reasonable answer. However, if the plume originates in a pool fire with little initial velocity, the dynamics of the fire-induced flow field must be included in the simulation. Simple empirical expressions, such as the those described by Briggs[8], often include entrainment parameters calibrated for different source characteristics, but these usually do not encompass the regime of large, buoyancy-dominated plumes such as those produced by burning large amounts of a liquid fuel.

THE ALOFT MODEL

Most of the assumptions required by integral models can be removed by taking advantage of the enormous advances in computational fluid dynamics that have occurred since most of these models were developed. As part of the process of evaluating the feasibility of using *in situ* burning as a remediation tool for large oil spills, the National Institute of Standards and Technology (NIST), under the sponsorship of the Minerals Management Service (MMS) and the Alaska Department of Environmental Conservation (ADEC), has developed a numerical model, ALOFT (A Large Outdoor Fire plume Trajectory), to predict the concentration of smoke and other combustion products downwind of a large fire. The original intent of the effort was to solve a simplified form of the equations of motion that govern the introduction of smoke and hot gases from a large fire into the atmosphere. It was assumed that the smoke plume was blown by a non-zero wind over relatively flat terrain (e.g., the sea surface or a flat coastal area). This version of the model is now referred to as ALOFT-FT™ (Flat Terrain)[9,10]. The flat terrain assumption is crucial, for it leads to the assumption that the windward component of the flow of smoke and hot gases from the fire *is* the prevailing wind, and the numerical problem is reduced to solving for the fire-induced components of velocity and temperature in a plane perpendicular to the prevailing wind. From a computational point of view, this simplifies the problem tremendously and allows for well-resolved computations of the plume dynamics as it rises and levels off in the atmosphere. High resolution in this case refers to the fact that motion on length scales of 5 m to 10 m is captured directly.

Initial calculations of the ALOFT-FT model were performed in 1993, and the results are documented in References [11,12]. In processing the results of the model, special attention was given to the downwind and lateral extent of ground-level particulate concentrations in excess of 150 µg/m^3 averaged over one hour. For meteorological conditions typical of the northern and southern coasts of Alaska, the calculations showed that hour-averaged particulate concentrations found at the ground downwind of a single continuous burn of a boomful of oil would not exceed 150 µg/m^3 beyond 5 km.

In follow-up reports[13,14], measurements from three mesoscale burn experiments were compared with ALOFT-FT predictions. The first experiment, the Newfoundland Offshore Burn Experiment (NOBE), was conducted by Environment Canada in August, 1993. The second, the Burning of Emulsions Test, was conducted by Alaska Clean Seas (ACS) in September, 1994. The third was a series of burns at the US Coast Guard Fire and Safety Detachment in Mobile, Alabama. For each series of burns, ALOFT-FT was run for the recorded meteorological and burn conditions, and the results were compared with data collected in the field. For all three large scale field experiments, the agreement between model and experiment was very favorable, and greatly increased the confidence in the numerical model.

The State of Alaska has asked EPA Region 10 to approve the use of the ALOFT model for predicting ground level particulate matter concentrations from oil spill control fires in regions of relatively flat terrain in Alaska. The environmental consulting firm EMCON Alaska, Inc., conducted a performance evaluation of the ALOFT model on behalf of the Alaska Department of Environmental Conservation (ADEC), and submitted their study to EPA Region 10 for review. The quantitative performance evaluation showed that the ALOFT model provides more accurate predictions of ground level particulate matter from oil fires. Compared to CALPUFF, the ALOFT model predictions showed lower absolute fractional bias and greater statistical correlation with the particulate concentration measurements that were made downwind of five experimental burns[15].

Presently, ALOFT-FT™ is available for public use, running under the Windows95®, Windows98® and WindowsNT® operating systems[16]. Documentation of the model is available on-line.

COMPLEX TERRAIN

The ALOFT model has been extended to scenarios involving complex terrain and multiple burns. The uniform wind assumption is no longer valid when the plume is to be tracked over complex terrain. Many regions in Alaska where burning might occur are characterized by complex terrain. In the region near Valdez, mountains rise several thousand meters within a few kilometers of the shore. With this new capability, more realistic, site-specific scenarios can be evaluated. ALOFT-CT™ (Complex Terrain) still makes use of the plume rise methodology employed by ALOFT-FT because the original simplification of the governing equations can be exploited to compute the rise of the plume until its stabilization height is reached. Then, the three-dimensional governing equations can be solved to provide a wind field over the complex terrain.

The extension of the model to incorporate complex terrain justifies the original decision to solve the fundamental equations of motion that govern the transport of the smoke and hot gases from the fires. The increased complexity of the problem makes it more difficult to apply conventional empirical models because the amount of field data with which to calibrate an empirical model to account for arbitrary terrain is very limited, plus the built-in assumptions of such a model are too simplistic to describe the plume as it is transported over a complex landscape. Because the ALOFT model solves the fundamental conservation equations that describe the plume structure and trajectory rather than relying on simplistic assumptions, it is a very flexible tool that can be adapted with confidence to increasingly complicated scenarios.

SAMPLE ALOFT CALCULATIONS

Consider the three-dimensional views of two simulations of smoke plumes originating in the Valdez Narrows, shown in Figure 1. The great difference in the plume trajectories, and the ground level concentration as well, is due to the difference in meteorological conditions. The temperature lapse rate in the first case is very nearly adiabatic (i.e., the temperature decreases with height at a rate of about 7°C/km). This essentially rids the atmosphere of the effects of the density stratification which tends to suppress vertical motion induced by terrain obstacles. Thus, in the first case where the atmosphere is neutrally stratified, the terrain plays less of a role in the plume's trajectory. Contrast this with the bottom figure. Here the atmosphere is very stable, and the temperature near the ground increases with height. Vertical motion is suppressed, forcing the air to flow around rather than over the terrain obstacles. Indeed the plume winds its way through the various passageways between the larger mountain peaks, leading to greater concentrations near the surface (see Figure 2). An excellent description of stratified flow past three-dimensional obstacles is given in Reference [17].

DOWNWIND SMOKE CONCENTRATION ESTIMATES

The calculations performed with the ALOFT model for various weather conditions and locations can be generalized and used to estimate the distance from a fire beyond which ground level concentrations of combustion products fall below regulatory thresholds. The combustion product most likely to violate ambient air quality standards is particulate, and the guideline recommended for *in situ* burning is 150 µg/m^3 (PM10) averaged over one hour.

The two most important factors determining this distance are the terrain height and the mixing layer depth *relative* to the elevation of the burn site. The mixing layer depth is the depth of the atmospheric boundary layer, which can be thought of as the cloud height. Taking a 0.044 m^3/s (1,000 bbl/h) burn as an upper limit for a single fire, 130 g/kg as the particulate emission factor, and 150 µg/m^3 as the hour-averaged concentration threshold, Table 1 lists the maximum distance as a function of terrain height and mixing layer depth. The mixing layer depth is loosely correlated with the temperature lapse rate, and the wind speeds considered were in the range from 1 m/s to 12 m/s. Note that the first row of the table corresponds to relatively flat terrain.

Table 1. Distance from a fire consuming 0.044 m^3/s (1,000 bbl/h) beyond which the hour-averaged ground level concentration of PM10 falls below 150 $\mu g/m^3$. These distances are expressed in units of kilometers (1 mi ≈1.61 km). Terrain Height and Mixing Layer Depth are relative to the altitude of the burn site. Modifications to these distances to account for different fire sizes and PM standards can be made according to the formula given by Equation (1).

Terrain Height (m)	**Mixing Layer Depth (m)**				
	0--100	**100--250**	**250--500**	**500--1,000**	**>1,000**
0--25 ("Flat Terrain")	5	4	3	2	1
25--250	10	8	6	4	3
250--500	15	12	10	8	5
>500	20	17	15	12	10

The maximum distance estimates can be modified to account for changes in the fire size, emission factor, concentration threshold, offshore burns, and multiple burns. If the given burn scenario calls for something other than a single fire on land consuming 0.044 m^3/s (1,000 bbl/h), and the ground level particulate criteria is something other than 150 $\mu g/m^3$ of PM10, then the distance from Table 1, D_{table}, should be modified according to the following formula:

$$D = D_{table} + 7\ ln\left[\left(\#\ of\ burns\right)\frac{150}{r_c}\frac{EF}{130}\left(\frac{BR\ (bbl/h)}{1,000\ (bbl/h)}\right)^{\frac{1}{3}}\right] + \left(d - d_{eq}\right)\ km \qquad (1)$$

The critical hour-averaged concentration ρ_c should be expressed in units of $\mu g/m^3$. The new U.S. Environmental Protection Agency (EPA) National Ambient Air Quality Standard (NAAQS) for particulate calls for 65 $\mu g/m^3$ for PM2.5 as well as the current PM10 standard of 150 $\mu g/m^3$. Emission factors for various PM sizes are reported in Reference [14]. The value 130 g/kg is for PM10; 82 g/kg for PM2.5. The Burning Rate, BR, is expressed in units of bbl/h *per fire* (1 bbl/h = $4.4 \times 10^{-5}\ m^3/s$). It is assumed that in the case of multiple burns, all the fires are of comparable size. Note that the Burning Rate, BR, can be expressed in terms of the burn area, burning rate or heat release rate as long as the value of the denominator (here given as 1,000 bbl/h = 0.044 m^3/s) is given in equivalent units. The distance d-d_{eq} accounts for the case where a plume originates offshore and is subject to less atmospheric turbulence over water before coming onshore. The distance d is the actual distance the plume travels over the water, and d_{eq} is given as:

$$d_{eq} = \frac{s_{w,marine}}{s_{w,coastal}} d \tag{2}$$

and represents an equivalent distance where the plume would be subjected to coastal rather than marine atmospheric conditions. The magnitude of the vertical wind fluctuation offshore is roughly half that of land, thus a good rule of thumb is to assume that the equivalent offshore distance, d_{eq}, is about half the actual distance, d. Note that the distance given by Equation (1) may be negative, in which case the distance from Table 1 would be reduced. However, this distance should not be reduced inside of a kilometer from the fire because of the unpredictable, transient nature of the near field environment that is not accounted for by the quasi-steady state model. This includes smoke traveling at low level due to smaller burning rates during fire ignition and extinction.

REFERENCES

1. Turner, J. S. *Buoyancy Effects in Fluids*. Cambridge University Press, Cambridge, England, 1973.

2. Turner, J. S. Proposed pragmatic methods for estimating plume rise and plume penetration through atmospheric layers. Atmospheric Environment, 19:1215-1218, 1985.

3. Wilson, R. B. Review of Development and Application of CRSTER and MPTER Models. Atmospheric Environment, 27B(1):41-57, 1993.

4. U.S. Environmental Protection Agency. User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Vol. II - Description and Model Algorithms, September 1995. Publication EPA-454/B-95-003b.

5. Perry, S. G. User's Guide to the Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS), Vol. I - Model Description and User's Instructions. U.S. Environmental Protection Agency, March 1989. National Technical Information Service Order No. PB89-181424.

6. DiCristogara, D. C. and S. R. Hanna. OCD: The Offshore and Coastal Dispersion Model, Volume 1: User's Guide. Sigma Research Corporation, Westford, Massachusetts, 1989. Report No. A085-1.

7. US Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. A User's Guide for the CALPUFF Dispersion Model, July 1995. Publication EPA-454/B-95-006.

8. Briggs, G. A. *Plume Rise Predictions*, Lectures on Air Pollution and Environmental Impact Analysis. pp. 50-111. American Meteorology Society, Boston, 1975.

9. Baum, H. R., K. B. McGrattan, and R. G. Rehm. Simulation of Smoke Plumes from Large Pool Fires. In: *Proceedings of the 25th International Symposium on Combustion*, pp. 1463-1469. The Combustion Institute, Pittsburgh, Pennsylvania, August 1994.

10. McGrattan, K. B., H. R. Baum, and R. G. Rehm. Numerical Simulation of Smoke Plumes from Large Oil Fires. Atmospheric Environment, 30(24):4125-4136, 1996.

11. McGrattan, K. B., A. D. Putorti, W. H. Twilley, and D. D. Evans. Smoke Plume Trajectory of *In Situ* Burning of Crude Oil in Alaska. Technical Report NISTIR 5273, National Institute of Standards and Technology, Gaithersburg, Maryland, October 1993.

12. McGrattan, K. B., H. R. Baum, and R.G. Rehm. Smoke Plume Trajectory of *In Situ* Burning Of Crude Oil in Alaska. In: *Proceedings of the 17th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* pp. 725-734. Environment Canada, Emergencies Science Division, Ottawa, Ontario, Canada, June 1994.

13. McGrattan, K. B., W. D. Walton, A. D. Putorti, W. H. Twilley, J. McElroy, and D. D. Evans. Smoke Plume Trajectory of *In Situ* Burning of Crude Oil in Alaska - Field Experiments. In: *Proceedings of the 18th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar*, pp. 901-914. Environment Canada, Emergencies Science Division, Ottawa, Ontario, Canada, June 1995.

14. McGrattan, K. B., H. R. Baum, W. D. Walton, and J. Trelles. Smoke Plume Trajectory of *In Situ* Burning of Crude Oil in Alaska—field experiments and modeling of complex terrain. Technical Report NISTIR 5958, National Institute of Standards and Technology, Gaithersburg, Maryland, January 1997.

15. EMCON Alaska, Inc., 4701 Business Park Boulevard, Suite 36, Anchorage, Alaska 99503-7166. Performance Evaluation of the ALOFT Model for Oil Spill Burns, September 1997. Project 55147-002.000 Task C2.

16. Walton, W. D. and K. B. McGrattan. ALOFT-FT™. National Institute of Standards and Technology, 1998. NIST SP 924, available via the Internet (http://fire.nist.gov).

17. Smolarkiewicz, P. K. and R. Rotunno. Low Froude Number Flow Past Three-Dimensional Obstacles. Part I: Baroclinically Generated Lee Vortices. Journal of the Atmospheric Sciences, 46:1154-1164, 1989.

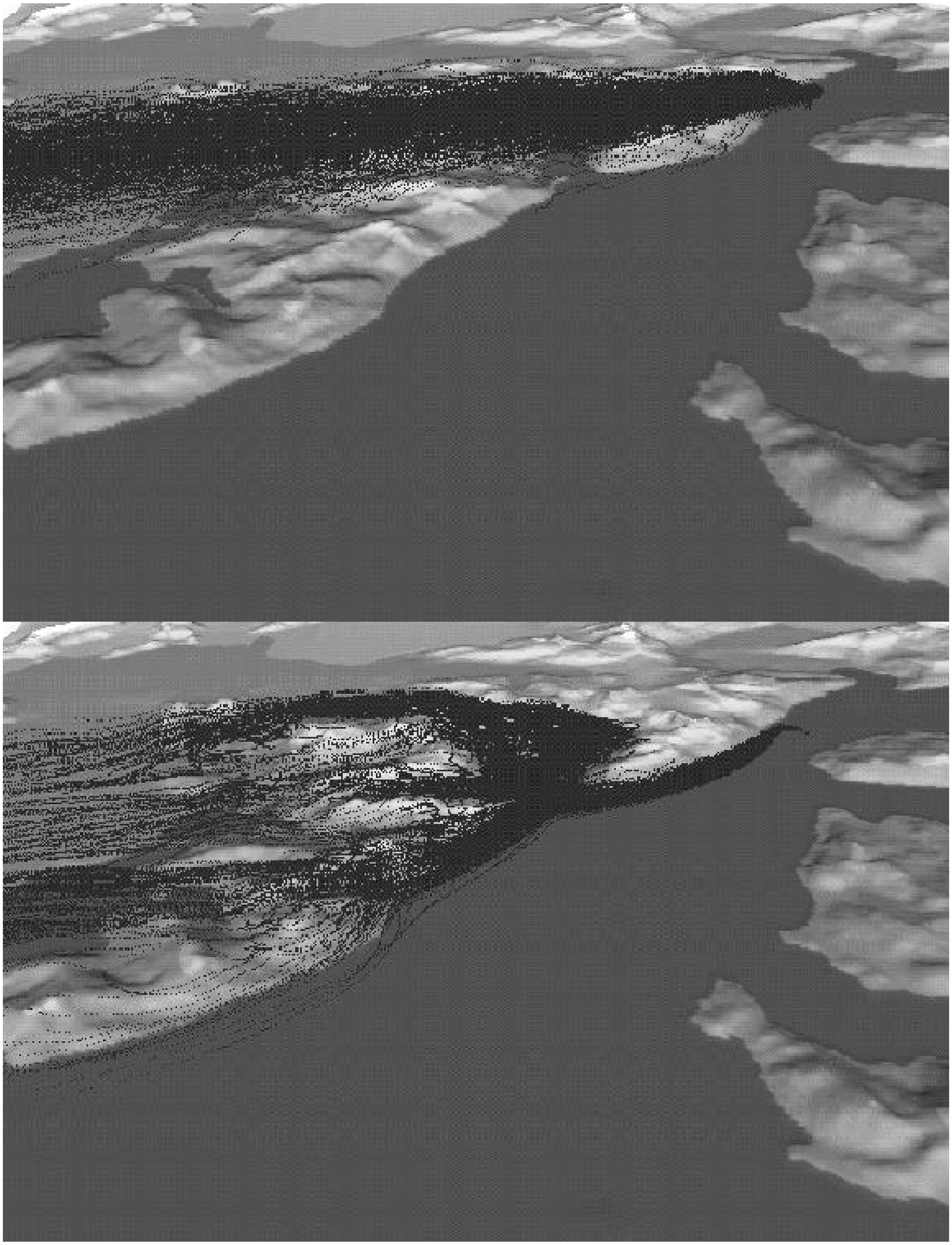

Figure 1. Three-dimensional views of smoke plumes originating in the Valdez Narrows, the entrance way to Port Valdez, Alaska. The top figure represents a case where the temperature of the

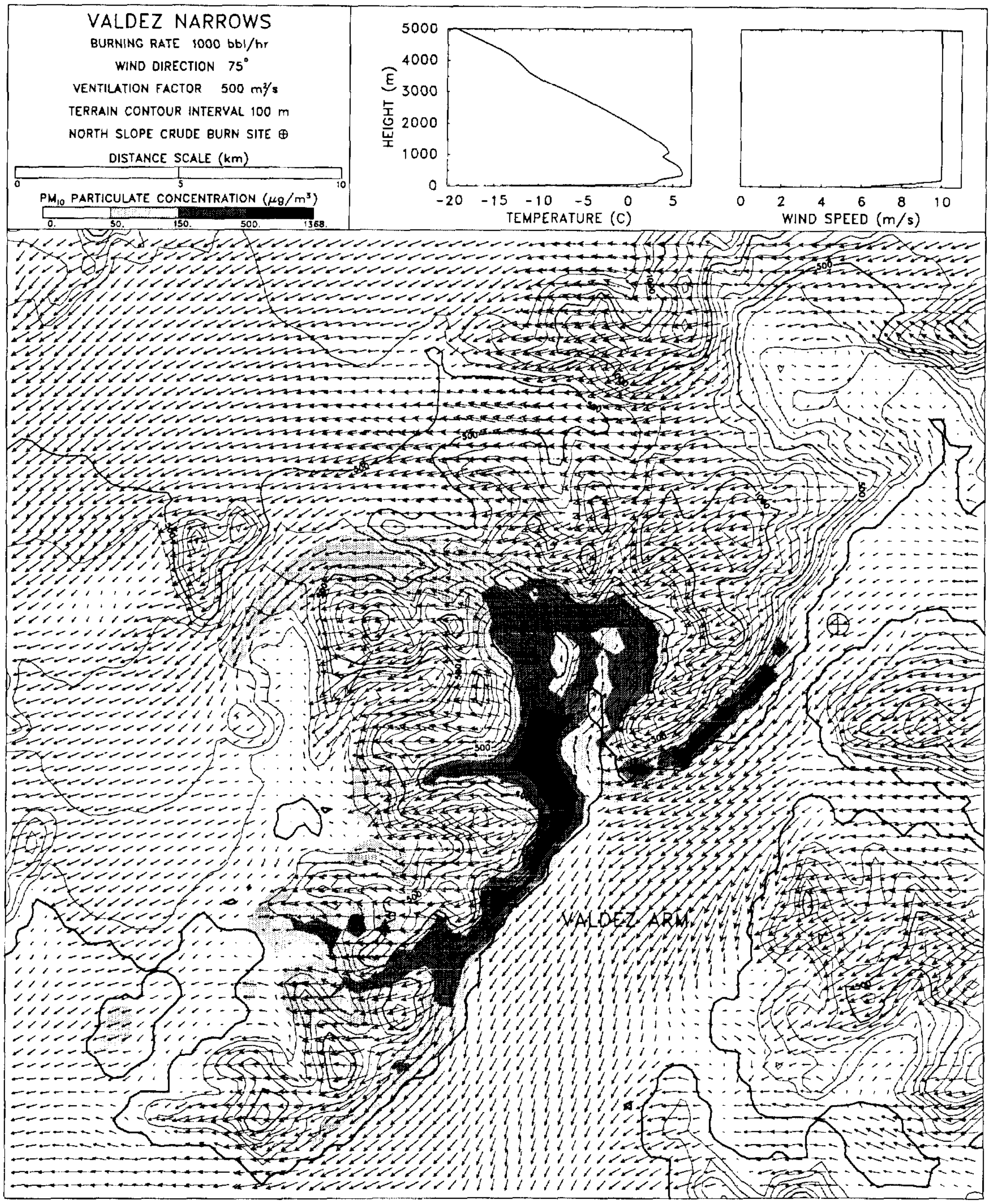

Figure 2. Ground level concentration of smoke particulate from a simulated smoke plume originating in the Valdez Narrows. This figure corresponds to the bottom picture in Figure 1.

ALTERNATIVE APPROACHES TO *IN SITU* BURNING OPERATIONS

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BACKGROUND AND OBJECTIVE

Beginning in the late 1970s and continuing through the 1980s, technology development and testing were undertaken to provide the equipment and techniques for the safe and efficient use of *in situ* burning as an oil spill countermeasure. These efforts have produced various devices to support open water burning of oil, including fire-resistant booms and ignition devices, which are currently part of the spill response arsenal (as described in Buist et al.[1]). This response technique was used in the initial stages of the *Exxon Valdez* response in March 1989 during which 350 bbl of Prudhoe Bay Crude were effectively burned using a fire-resistant boom as a containment and incineration device. This modest accomplishment, in a situation where all other spill response techniques appeared marginally effective, provided renewed interest in developing *in situ* burning as a countermeasure of choice for major, open water spills.

Significant efforts have been made since *Exxon Valdez* to improve fire-resistant boom design, refine operational procedures, and resolve issues associated with the air contamination that results from burning. These research efforts culminated in an international, multi-agency test burn in 1993 offshore of St. Johns, Newfoundland known as the Newfoundland Offshore Burn Experiment or NOBE (Environment Canada [2]). The experiment verified that *in situ* burning operations can be safely and effectively carried out with burn efficiencies exceeding 90%, resolved many of the uncertainties regarding air contamination, and confirmed the overall viability of *in situ* burning as a response tool. The NOBE test burn also showed that current fire-resistant booms will be subject to deterioration from the thermal and mechanical stress resulting from burning at sea. More recent burning tests have been conducted to determine the durability of existing booms and verify the American Society for Testing and Materials (ASTM) fire-resistant boom testing standard (McCourt et al.[3]). These tests have shown that the service life of boom sections in the apex of the boom remains on the order of 6 hr to10 hr. This suggests an upper limit to the duration of a burn operation after which the boom must be refurbished and redeployed.

The objective of this study was to provide a "second look" at the *in situ* burning of oil spills focusing on two plausible scenarios under which the current fire-resistant boom approach may be inadequate. The first scenario considered is a spill involving a longer-term, continuous release of oil from a fixed source, such as an oil platform blowout. The second is a large spill in a shallow, coastal marsh or river where deploying and/or towing a standard fire-resistant boom is precluded by water depth, obstructions, and the remoteness and environmental sensitivity of the area. Two general approaches were investigated. The first is the use of a towable oil spill burning device which can be used in conjunction with containment booms and skimmers to allow for prolonged *in situ* burning operations in open water. The second is the use of easily deployed fire-resistant containment devices for shallow waters in remote, environmentally sensitive areas, where the logistics of deploying and operating conventional spill response equipment are often complicated. Both of these options were researched and analyzed to determine relevant technologies, viable concepts, engineering design feasibility, and operational requirements and constraints. The goal was to identify viable concepts (systems, equipment and procedures) that can be carried forward for further research, development, test and evaluation.

APPROACH

The first task in the study was a general assessment of the characteristics of spills where these applications might be encountered. This assessment included a review of past spills as documented in the literature, and a review of current contingency plan spill scenarios that present long-term continuous source and shallow-water burning opportunities. Based on the actual and expected spill situations, design scenarios were developed which are representative of the offshore and nearshore conditions where alternative approaches to *in situ* burning may be effectively applied. The design parameters considered included the size of the spill, spill rate, environmental conditions (wind speed, wave conditions, water depth, current speed), and operational and logistics constraints and requirements (distance offshore, availability of staging areas and access roads, availability of support vessels). The design scenarios developed included the following:

- Offshore Platform Spill in the Gulf of Mexico
- Offshore Platform Spill in Cook Inlet
- Onshore/Offshore Platform Spill, Prudhoe Bay
- Shallow-Water Spills for Marshes, Mud Flats, Lagoons, and Tidal Creeks
- Shallow-Water Spills in Rivers and Along Shorelines

For the platform spills, the total spill volumes ranged from 50,000 bbl to180,000 bbl, with initial spill rates of 5,000 bbl/day to 12,000 bbl/day, decreasing to 1,000 bbl/day. Hence the targeted oil burning capacity for alternative systems is 5,000 bbl/day to 10,000 bbl/day. Spill duration ranged from 15 days to 30 days. The distance to the nearest staging area ranged from 5 NM to 50 NM. Wind speeds of 0 kt to 20 kt are expected, with seas l ft to 3 ft and currents up to 1 kt. Mechanical recovery is initiated but not adequate in view of the spill volume and shoreline impact is likely. *In situ* burning is authorized.

The shallow water spills involve light crude or fuel oil which is transported along a river or into shoreline areas. Water depths are 1 ft to 3 ft; current speeds are 0 kt to 2 kt. The area is remote and environmentally sensitive which precludes intensive mechanical recovery operations. Because of the remoteness of the area, and lack of other viable cleanup alternatives, *in situ* burning is authorized.

Based on the potential scenarios and design parameters, several conceptual systems were proposed for in-depth evaluation. Insight on how these conceptual systems could be configured was largely derived from previous oil spill burning technology development and testing efforts (e.g., for conventional fire-resistant booms, novel oil containment techniques, oil spill igniters, shore-based incinerators and flaring burners, and smoke-suppression techniques), as well as the current operational doctrine for carrying out *in situ* burning using fire-resistant boom. Development of the conceptual systems focused on integrating some of these proven or potentially viable technologies to address the offshore, continuous source and shallow-water applications. The basic systems proposed included:

Concept I	A simple, oil burning barge produced by modifying an existing barge hull.
Concept IIA	An oil burning barge using an enhanced air flow scheme integrated into an existing barge hull (a refinement of Concept I).
Concept IIB	An oil burning barge using an existing barge hull and a state-of-the-art oil flaring burner designed for offshore oil production operations.
Concept III	A simple, modular oil burning barge specifically designed and constructed for this purpose.
Concept IV	An air bubbler system for oil containment and burning in shallow water.
Concept V	A simple, fire-resistant fence boom for oil containment and burning in shallow water.

A strategic level engineering and operational analysis was conducted to determine the overall feasibility of the conceptual systems proposed. The engineering analysis investigated the feasibility of building, assembling and modifying the necessary platforms and equipment to form a complete system. Anticipated performance in terms of oil burning capacity, stability, seakeeping, and durability were investigated. System cost and the ability to meet inspection and certification criteria also were considered. The engineering feasibility assessment was largely based on first-order calculations, current engineering practice, and past experience with such systems and equipment. As the systems were only described at a conceptual level, cost and construction time projections represent order of magnitude estimates. The operational analysis investigated the transportation, deployment and operational support requirements required in implementing the alternative approaches in an actual spill situation. Transport and deployment logistics requirements, operations monitoring and control procedures, occupational and environmental safety considerations, and policy constraints were analyzed at a strategic level.

Based on the results of the engineering and operational analysis, more detailed designs for each of the basic concepts were developed, and a preliminary assessment made of the overall feasibility of producing such a system. Advantages and constraints were summarized, and second-level conceptual drawings developed depicting how the basic concepts might be implemented. In addition, a hindcast analysis was conducted of past significant spills where the alternative approaches to burning might be considered, to determine if these concepts could have been effectively implemented given the constraints of the moment, to significantly impact the success of the response. This provides insight on the general applicability and benefit of the new systems if they are carried forward for further development and testing. There is little benefit in developing a highly effective spill response technology that is seldom implemented. The results of the study also were reviewed by a panel of government and industry experts to solicit guidance on the viability of these concepts and issues that still needed to be addressed.

RESULTS

Based on the analysis of the engineering design and operational considerations for the generalized concepts, the following system configurations were developed and the feasibility of each assessed. The discussion for each system summarizes the important findings with respect to the feasibility of each of the concepts, and provides further insight into the configuration and attributes of the various devices envisioned. Drawings are provided for the designs embodied in Concept IIA, IIB, III and V to give an overview of how each approach might be implemented.

Concept I - A Simple Oil Burning Barge Using a Modified Ocean Tank Barge Hull

An existing ocean tank barge hull is obtained and the center tanks removed to produce a stable platform with a 150 ft x 25 ft interior burn area to provide a burn capacity of approximately 10,000 bbl/day. The deck is left in place over the first two center tanks to maintain structural strength. Vents are installed in these decks to prevent buildup of hydrocarbon vapors. Transverse bulkheads are left in place at 1 ft below the waterline to enhance structural strength. An inclined plane and foil have been added to enhance oil collection, and prevent flashback to the oil slick itself. Fire-resistant boom (near the barge) and foam boom or inflatable boom (away from the barge) are mounted on the bow to funnel oil into the device.

Ideally, a simple water cooling system will allow the interior hull and decks to withstanding the heat generated by the burning oil, such that extensive hull fortification (using stainless steel) and insulation will not be needed. The water pumps can be located in the barge hull, in the forward sections away from the burn area. Ignition is provided by a simple propane or diesel-fired ignition system at the rear portion of the burn area. Fire suppression is provided by a simple CO_2 compressed gas system controlled remotely by telemetry from the towing vessel.

The primary advantage of this device is its simplicity and relatively low cost compared to the other alternatives (approximately \$625K), although the cost will escalate if stainless steel fortification and insulation are required (up to \$1M). The primary disadvantage is its size which requires transport by sea, such that the device must be pre-staged within 250 miles of the spill site to satisfy Tier II response criteria. The significant advantage of this device over standard fire-resistant boom is its extended service time on-scene.

Concept IIA and IIB - Enhanced Oil Burning Barge Using a Modified Ocean Tank Barge Hull

Concepts IIA and IIB are more sophisticated versions of Concept I and are designed to provide enhanced burning rates and suppress emissions to a level where they can be used in nearshore areas if necessary. Two versions of this device were considered, one using two enhanced airflow combustion devices (shown in Figure l), and the other using a state-of-the-art oil and gas flaring system (shown in Figure 2). Both designs utilize the modified oceangoing barge hull described in Concept I.

For Concept IIA, the oil combustion takes place in the aft section of the center tank area. The oil passes into a burn chamber equipped with airflow enhancement similar to that investigated at the University of Arizona (Franken et al.[4]). Enhanced airflow is provided by a passive air scoop located in front of the burn compartment along with direct air injection supplied by blowers located in portable ISO containers on deck.

Ideally, this enhanced air circulation and stack arrangement would provide a 3,000 bbl/day burn capacity (1,500 bbl/day for each combustion unit) with reduced emissions (particularly reduction of visible emissions). A similar combustion enhancement scheme was proposed for an Arctic Incinerator Barge described by Glosten et al.[5]. Concept IIA would have to be inspected and certified by the USCG and EPA. The current operation scheme does not call for personnel being on board. The cost of the device is somewhat higher than Concept I (perhaps $1.2M to $1.7M). The primary advantage of the device over the standard fire-resistant boom approach is greater service life on scene, better burn efficiency and reduced emissions possibly allowing use in nearshore areas. The drawbacks (as with Concept I) are its size and limited transportability, and the additional complexity and cost.

For Concept IIB, the high-capacity, low-emissions burning capability is accomplished with a high-volume flaring burner such as the SuperGreen Burner developed by Expro Ltd. in the UK. In this concept, the oil is collected in the after section of the center tank area and pumped directly to the burner itself. The burner heads are mounted on a boom at the stern of the barge to reduce thermal radiation and allow emissions to travel downwind away from the barge. No combustion takes place within the barge. Several ancillary systems are required, including three compressors to supply atomizing air to the burner heads, a weir skimmer device and pump to supply oil to the skimmers, and a water pump and spray system to provide a back spray of cooling water behind the burner head to protect the hull from thermal radiation. The current two-burner head model is capable of providing a burn capacity of 10,000 bbl/day. The burners can handle emulsified oil with up to 50% water content. The emissions produced can be kept well within UK regulatory limits, with virtually no visible emissions.

Concept IIB probably can be inspected and certified by USCG and EPA as a vessel and incinerator. The use of flaring burners on offshore platforms is routinely permitted by the Minerals Management Service. Additional USCG and U.S. Occupational Health and Safety Administration (OSHA) criteria will have to be satisfied as the complexity of the flaring burner and supporting machinery will probably require technicians to be aboard the barge during operation. Personal protection and emergency evacuation equipment and procedures will be required, as will specialized training of the operating personnel.

The primary advantage of Concept IIB is its use of proven technology to provide a highly efficient, very low emissions burn. The disadvantages are the complexity and the projected cost (probably in excess of $2M). Transportability is improved in that the burner heads and supporting equipment can be moved and transported (as is routinely done in offshore platform applications). Only the barge hulls need to be pre-staged near potential spill sites.

Concept - III Modular, Transportable Oil Burning Barge

Concept III is essentially an adaptation of the basic scheme described in Concept I, in an attempt to make the design smaller and modular (ability to be disassembled for transport) such that it can be moved by truck or aircraft. This will allow the device to be pre-staged at a central location and still respond to spills around the country and the world. A drawing of the device (100 ft version) is provided in Figure 3.

The basic design scheme for the barge hull is similar to that developed by Webster Barnes, Inc., for their HIB skimmer. This device uses a system of inclined submersion plane skimmer, flow- enhancing foil, and horizontal baffles to provide an effective oil skimming and separation capability. In normal operation the oil is pumped from the device into a storage barge or dracone (flexible oil bladder). In the application envisioned, the oil would be burned in the device itself. With regard to auxiliary systems, a simple propane ignition and CO_2 fire-suppression system could be installed with the compressed gas cylinders mounted outboard of the side flotation chambers and shielded from the heat and flame. Cooling water could be supplied by a pump float towed behind the vessel. Constructing the modular oil burning version of the device will involve scaling up the size of the hull, changing the hull material to steel rather than aluminum, and fabricating the device in sections which can be disassembled for transport.

Webster Barnes, Inc., provided an initial hull design for a 180 ft and 100 ft version of the device. The interior burn areas are 4,102 ft^2 (146.5 ft x 28 ft) for the 180 foot model, and 1,622 ft^2 (70.5 ft x 23 ft) for the 100 foot model. This provides a burn capacity of 11,907 bbl/day and 4,721 bbl/day respectively. A modular, air-transportable version of the device probably will be 75 ft to100 ft in length and have a burn capacity of 4,000 bbl/day to 5,000 bbl/day.

Making the design modular would require some additional engineering such that the device could be transported and assembled in sections. As for cost, Webster Barnes, Inc. estimates that the conventional construction versions of the 180 ft and 100 ft hulls would cost $1,800K and $710K respectively. Converting the 100 ft version to a modular design would increase the cost approximately 65% ($1,171K).

The major advantages of the Concept III device are its transportability and its durability as compared to fire-resistant booms. The primary disadvantage of the device is its initial cost, although this may be offset by the savings in only having to produce one or two devices to provide Tier II response coverage for the entire country. Because of its transportability, maneuverability, and simplicity, Concept III appears to be a highly viable option for conducting long-term burning operations.

Concept IV - Air Bubbler System for Shallow Water

This system would consist of an air blower (1500 CFM at 10 psi), a power pack (diesel-driven hydraulic supply to power the blower), 150 ft of flexible bubbler hose weighted with galvanized chain, and a hose reel for ease of transport and deployment. This system is similar to proposed by Williams and Cooke (1985). All of these components can be easily acquired or fabricated. Total weight of the system is 2,050 lbs; total volume is 150 ft^3 to 200 ft^3; and total cost is approximately $14K.

Because the system is composed of several components, it can transported by a small truck or helicopter. The major questions regarding Concept IV are its effectiveness in wind and currents (limited to wind speeds less than 10 kt; current speeds less than 1.0 kt), and the frequency of spill conditions that call for its use.

Concept V - Simple, Fire-Resistant Fence Boom for Shallow Water

Concept V is the simplest of all approaches considered. It involves the use of a simple, fire- resistant fence boom (e.g., constructed of corrugated sheet metal) which can be anchored in shallow-water areas using stakes driven into the sediment. A simple flotation scheme could involve 55 gal drums attached to the boom sections. The basic design and deployment scheme are depicted in Figure 4. This boom can be used to concentrate and burn oil in shallow-water marsh areas, mud flats or along the banks of creeks and rivers. It could be used in conjunction with conventional boom when diverting oil in rivers and estuaries toward shallower water near the shore for burning, possibly using the river bank itself as part of the oil barrier. Each boom section is 2 ft x 10 ft (total weight 2 lb/ft to 3 lb/ft) for ease of deployment. The boom is anchored in shallow water with re-bar rods 4 ft to 6 ft in length. The total cost of a 500 ft boom is estimated at $10K.

Concept Application Hindcast Analysis

The hindcast analysis was based on a number of significant vessel (tanker and barge) and platform spills over the past 30 years. For the most part, the larger spills were reviewed to determine the utility of the floating incineration devices (Concepts I through III). In addition, a number of spills in marsh and river environments were reviewed to assess the utility of Concepts IV and V.

Concepts I and II were directly applicable in 5 of 39 spills surveyed, and potentially applicable in 4 of 39 spills. Most of these spills were caused by well blowouts and platform casualties. This applicability assumes that the Concept I and II devices are located in the areas where these blowouts generally occur (e.g., Gulf of Mexico, North Sea, Persian Gulf).

Concept III was directly applicable for 5 spills, and potentially applicable for 5 more. However, this overlooks the utility of Concept III in augmenting responses involving mechanical recovery where it can be used as an offshore burning device for oil recovered in remote locations.

Concept IV was found to be directly applicable in only one spill, and potentially applicable in only 4 spills, Concept V was found to be directly applicable in only 1 spill and potentially applicable in 5 spills. However, the utility of Concepts IV and V may be somewhat underestimated by the hindcast as the devices may be effectively employed in smaller major and medium spills as well as the more significant major spills surveyed.

CONCLUSIONS

Based on the results of the analysis and the comments and suggestions of the technical review panel, the following overall conclusions were drawn:

Concept I - This concept now appears less viable than was originally envisioned. Although oceangoing barge hulls are readily available, the cost of modifying and fortifying the hull, and installing the required cooling and ignition systems, will probably drive the cost to $lM or more. Because of the limited response range, several systems will be required, ideally pre-staged in high offshore oil production areas (e.g., Gulf of Mexico, Persian Gulf).

Concept IIA and IIB - Concepts IIA and IIB essentially achieve the same result--processing a large quantity of oil with a reduction in emissions as compared to open burning. Concept IIA represents a technology which has yet to be fully developed and implemented, whereas the technology for Concept IIB exists and is proven. Both Concepts IIA and IIB are in the same general price range. If the size, cost and complexity of the flaring burner assembly can be reduced, the use of the flaring burner integrated with a skimming barge may be worth revisiting.

Concept III - Of the four oil burning barge concepts investigated, Concept III appears to be the most promising, particularly for a modular air-transportable unit. Although the processing capacity is decreased (4000 bbl/day to 5000 bbl/day) from Concepts I and IIB, the ability to transport by land or air is an overwhelming advantage in terms of its availability to respond to a spill. The simplicity of the unit, and its ability to operate in high currents also is attractive.

Concept IV - Although Concept IV appeared attractive at the outset of the study, the problem of limited hose length when using a blower, and increased size and weight when using a compressor, now make this alternative far less feasible.

Concept V - This concept is simple, inexpensive and reliable and can be implemented using readily available materials. Refinements to the design might include a mechanism for quickly connecting each section. It also should be noted that the barrier is useful for shallow water containment even when burning is not permitted or not desirable.

REFERENCES

1. Buist, I.A., S.L. Ross, B.K. Trudel, E. Taylor, T.G. Campbell, P.A. Westphal, M.R. Myers, G.S. Ronzio, A.A. Allen and A.B. Nordvik. The Science, Technology, and Effects of Controlled Burning of Oil Spills at Sea. Marine Spill Response Corporation, Washington, D.C. MSRC Technical Report Series 94-013, 363 p., 1994.

2. Environment Canada, Data Compilation, Newfoundland Offshore Burn Experiment (NOBE) Report, Emergencies Science Division, Environmental Technology Centre, Environment Canada, Ottawa, Ontario, 1997.

3. McCourt, J., I. Buist, B. Pratte, W. Jamieson and J. Mullin. Testing Fire Resistant Boom in Waves and Flames Proceedings of the Twentieth Arctic and Marine Oil Spill Program Technical Seminar. Environment Canada, Ottawa. pp. 823-839, 1997.

4. Franken, P., D. Perry, R. Randt, R. Petersen and C. Thorpe. Combustive Management of Oil Spills--Final Report, University of Arizona, prepared for U.S. Department of Energy, Advanced Energy Projects Division, Grant No. DE FGO 2-9@ER- 12 102, 1992.

5. Glosten Associates, Inc., D.F. Dickins Associates, Ltd., and S.L. Ross Environmental Research Ltd. Conceptual Design for a 144' x 60' x 11' Arctic Environment Incinerator Barge. Report to Shell Western E&P, Anchorage, AK, 1991.

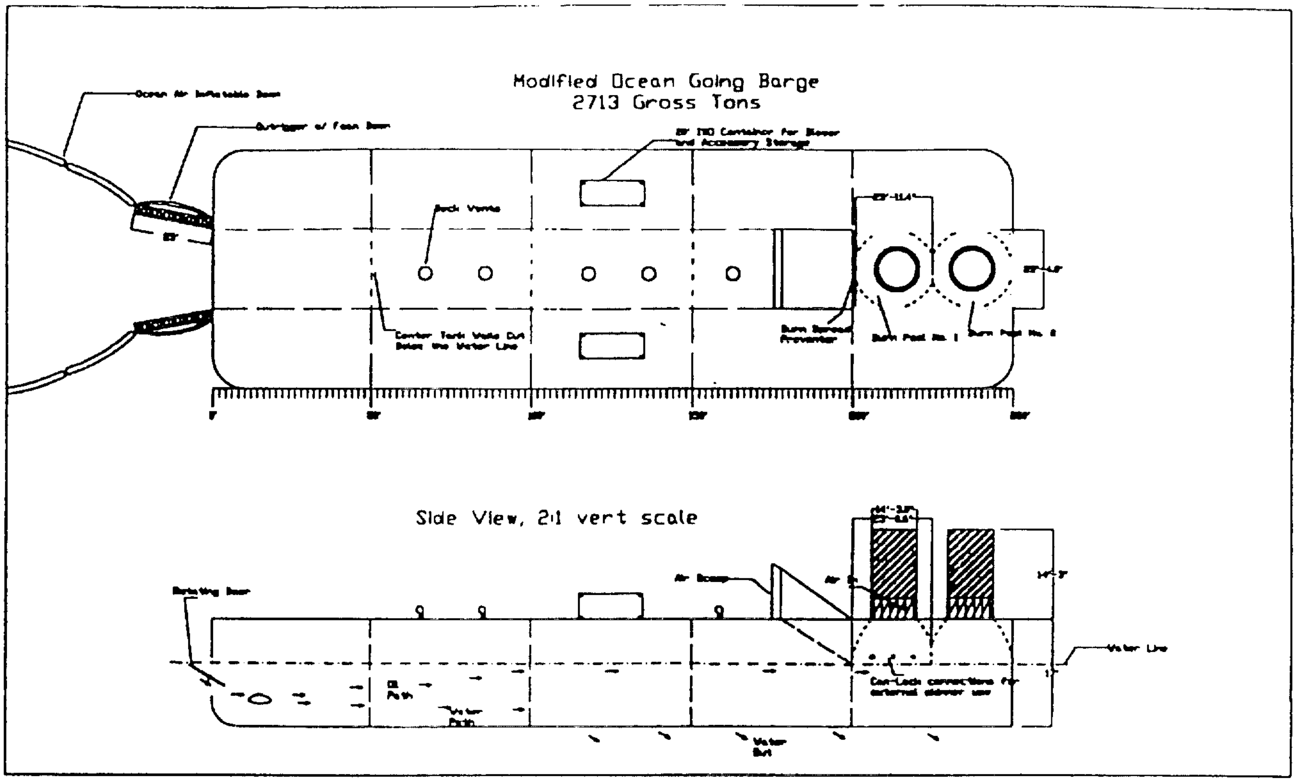

Figure 1. Basic Design for Concept IIA- Oil Burning Barge With Emissions Control Device

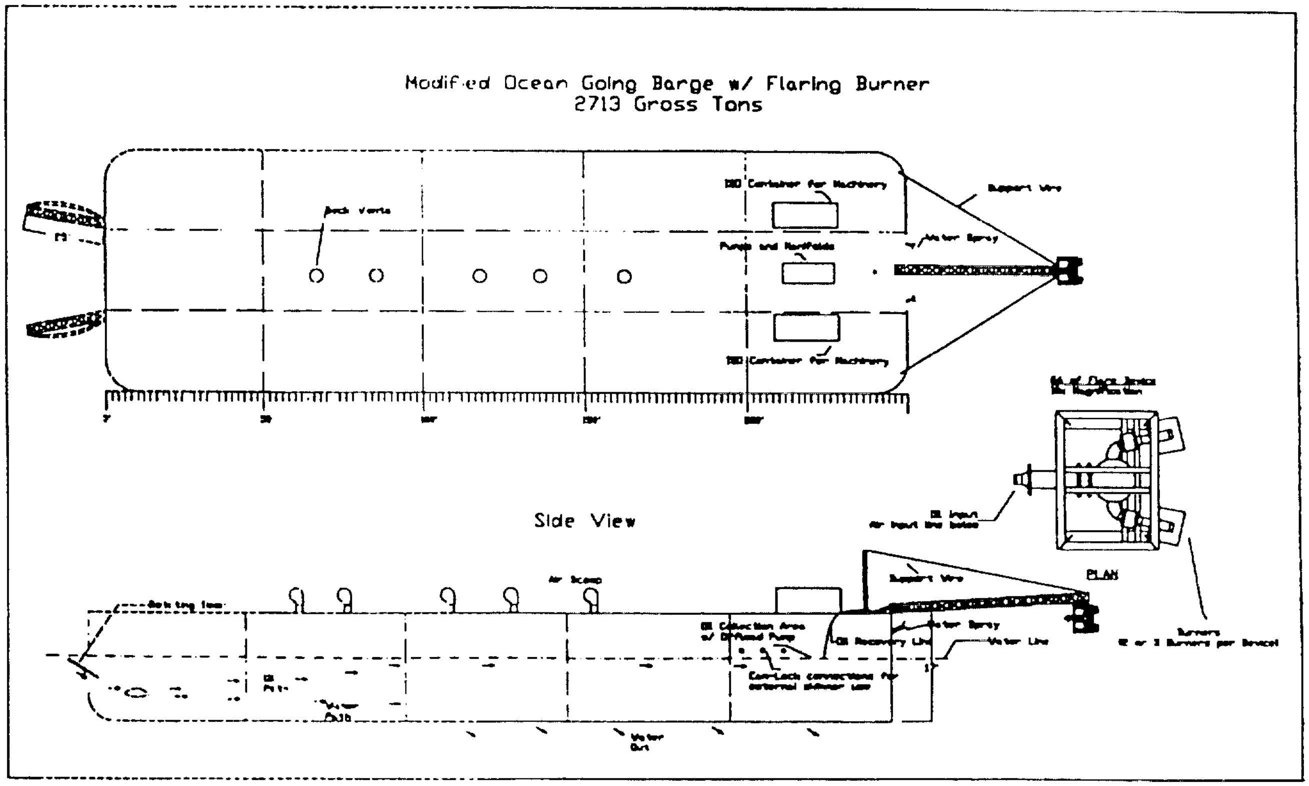

Figure 2. Basic Design for Concept IIB - Oil Burning Barge Equipped With Flaring Burner

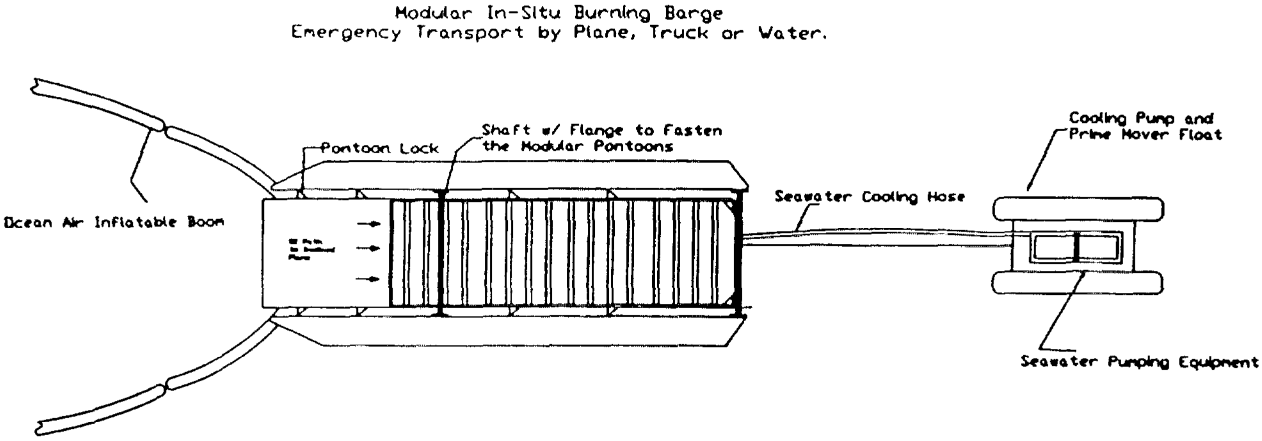

Figure 3. Basic Design for Concept III - Modular, Transportable Oil Burning Barge.

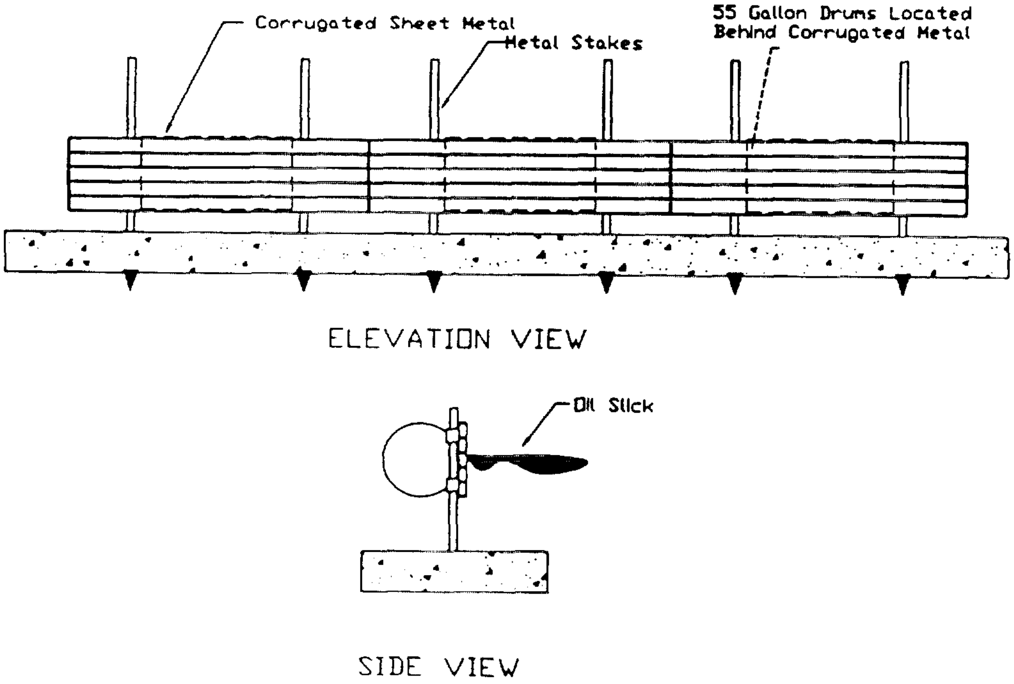

Figure 4. Basic Design for Concept V - Simple, Fire-Resistant, Shallow Water Fence Boom.

ENVIRONMENTAL EFFECTS OF *IN SITU* BURNING OF OIL SPILLS IN INLAND AND UPLAND HABITATS

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SUMMARY

In situ burning of inland and upland habitats is an alternative oil spill cleanup technique that, when used appropriately, may be more environmentally acceptable than intrusive manual, mechanical, and chemical treatments. There have been few published reports documenting the environmental effects of *in situ* burning in inland and upland habitats. Thus, this study, sponsored by the American Petroleum Institute, used two approaches to increase the knowledge base and improve the appropriate use of *in situ* burning: (1) detailed review of published and unpublished *in situ* burn case histories for inland and upland spills; and (2) summaries of fire effects and other information from the literature on fire ecology and prescribed burning. Thirty-one case histories were summarized to identify the state of the practice concerning the reasons for burning, favorable conditions for burning, and evaluations of burn effects. The fire ecology and effects summaries included information from the extensive knowledge base surrounding wildfire and prescribed burning (without oil) as a natural resource management tool, as well as fire tolerance and burning considerations for dominant vegetation types of the United States. Results from these two approaches should improve the application of *in situ* burning for inland and upland spills.

INTRODUCTION

The primary objective of this study was to identify the environmental conditions under which burning should be considered as a response option for oil spilled in inland and upland habitats. Two different approaches were used: (1) documenting the state of the practice from spill case histories where burning was used; and (2) extracting information from the extensive literature on fire ecology and prescribed burning. Combined, these two approaches provide the best available guidance on when burning should and should not be considered for a specific spill in inland and upland areas. Issues relating to human health and air quality were not directly addressed in this study.

CASE HISTORIES

Previous literature searches[1,2], recent publications, and personal contacts were used to identify 31 case histories of spills or experiments where oil was burned in inland and upland habitats (see reference [3] for complete references and contacts). These case histories were reviewed and standard incident summary sheets were generated for each case history. Generally, burns were conducted mostly in marshes and open fields. Nearly half of the burns of a known volume of spilled oil were for quantities of less than 1,500 l. The most common type of oil burned was crude oil; there was only one case where a heavy crude oil was burned. Post-burn monitoring was seldom conducted for any period of time. Burning, especially of small spills, is routinely conducted in some states, but there is little documentation available other than the fact that the oil was burned.

The case histories did, however, provide information on the state of the practice in terms of how *in situ* burning is used in inland and upland areas. In the past, spilled oil has been burned for the following reasons:

- To quickly remove oil to prevent its spread to sensitive sites or larger areas;
- to reduce the generation of oily wastes, especially where transportation or disposal options were limited;
- where access to the site was limited, by shallow water, soft substrates, or the remoteness of the location;
- as a final removal technique, when other methods began to lose effectiveness or became too intrusive.

Favorable conditions for burning were identified from the case histories, as follows:

- Remote or sparsely populated sites;
- mostly herbaceous vegetation (e.g., fields, crop land, marshes);
- dormant vegetation (not in active growing season);
- unvegetated areas (e.g., dirt roads, ditches, dry streambeds);
- in wetlands, presence of a water layer covering the substrate;
- in cold areas, presence of snow and ice which provides natural containment and substrate protection;
- calm winds;
- spills of fresh crudes or light refined products which burn more efficiently.

Operational and post-burn considerations developed from the case histories include:

- Avoid physical disturbance of the vegetation and substrate;
- when oil does not ignite readily, an accelerant may be needed;
- a crust or residue (which may hinder revegetation) is often left behind after burning, and may need to be broken up or removed;
- erosion may be a problem in burned areas if plant cover is reduced;
- vegetation in and adjacent to burn site can be affected by burning, including long-term changes in the plant community;
- burning can severely impact organic soils, such as peat found in certain wetlands.

FIRE ECOLOGY AND PRESCRIBED BURNING

In addition to the case histories, applicable information was gathered from the fields of fire ecology and prescription burning (in the absence of oil). Prescribed fires are often used as a forest and range management tool, and are often conducted for the same reasons as *in situ* burning: fire can be less damaging, more effective, and less costly than chemical and intrusive mechanical methods[4]. The fire ecology and prescribed burning literature was searched for both general guidelines as well as species-specific profiles on fire ecology and effects, providing valuable summaries on the effects of burning (in the absence of oil) on plant communities. There are many lessons already learned by prescribed fire practitioners and fire ecologists which are directly applicable to the use of *in situ* burning of spilled oil. Major fire ecology and prescribed burning references that were consulted[4-6].

In addition to literature sources, the U.S. Department of Agriculture's (USDA) Forest Service maintains a Fire Effects Information System (FEIS) which was used as the major source for reviewing and summarizing information on the ecology and effects of fire on specific plant species[7]. This database can be accessed over the World Wide Web at the following Web address: http://www.fs.fed.us/database/feis/welcome.htm. The FEIS contains literature summaries and case histories from a wide body of sources. Pertinent database fields include the following: fire ecology and adaptations; post-fire regeneration strategy; immediate fire effect; plant response to fire; fire management considerations; and fire case studies. For this study, information on fire effects and ecology of over 200 dominant plant species of U.S. ecoregions were summarized from the FEIS database. As an example, a summary for one species is provided in Table 1 (see Reference [3] for other species). Such summaries should provide spill responders with better information on the potential response of different habitat types and plant species to *in situ* burning. Major points from the literature review and the FEIS ecoregion species summaries on fire effects (in the absence of oil) are discussed below by major vegetation type.

Trees/Forests

Even if they are not killed by fire, trees generally take a long time to recover to pre-fire levels of structure and dominance relative to smaller, faster growing shrubs and grasses. Fire may wound or scar trees, providing entry points for pathogens (e.g., fungi, insects) that could lead to delayed impacts or mortality as a result of fire. *In situ* burning in most forested areas should be discouraged; however, for certain types of settings and communities, *in situ* burning of surface vegetation within forested areas may be reasonable. Burning might be reasonable for open or savanna-like forest communities with tree species that are at least moderately fire tolerant, especially if fire threat to trees is minimal or actively minimized. *In situ* burning might also be reasonable for special fire-prone or fire "adapted" forest species or communities under certain conditions, even if trees will be directly at risk from fire.

Shrubs and Associated Communities

Woody shrubs may be lumped with trees in certain respects, in that they look similar and thus may be perceived as fire sensitive; however, the shrub species examined showed a wide range of fire sensitivity, with many species being very fire tolerant. Several highly fire-tolerant species examined might be good candidates for *in situ* burning. Shrubs are usually top-killed by fire, but many sprout vigorously from belowground parts and recover quickly from fire. It should be kept in mind that dense shrub thickets can create fire hazards and carry fire to unwanted areas. Also, some very fire "adapted" shrub species and communities also are highly flammable, presenting additional fire hazards.

Grasses/Grasslands

Many graminoids (e.g., grasses, sedges) are fire tolerant and appear to be good candidates for *in situ* burning. Most of the species examined respond better during dormant season burns, and when soil conditions are moist or wet, so that roots, rhizomes, and organic soils are less likely to be damaged. For native grasslands, natural and prescribed fires are typically low intensity and fast moving; high intensity, slow burning fires such as those that might be produced by *in situ* burning of oil may be more damaging than typical fires. Native grassland species include many warm season grasses, dormant in cool season months. Many non-native species which occur in prairies, pastures, fallow fields, etc. are cool season grasses, whose growing season may correspond or overlap with the typical dormant period of warm season species. The types of grass species present (warm season, cool season, or both) could be an important factor when plant dormancy and other seasonal concerns are considered in relation to *in situ* burning. Tallgrass prairie (e.g., bluestem) grasslands of the eastern plains appear to be more fire tolerant than mixed and shortgrass prairie (e.g., grama-buffalograss) grasslands of the central and western plains, where conditions are more arid. *In situ* burning may have greater potential in areas with tallgrass prairie, where damage to native vegetation is less likely. Finally, although many grasses are fire tolerant, some species or growth forms can be much less so. In general, bunchgrass species or forms are often more fire sensitive than low-growing, rhizomatous grasses. Perennial needlegrasses (*Stipa* spp.) are reported to be the least fire tolerant of the bunchgrasses, and may not be good candidates for *in situ* burning.

Desert Habitats/Cacti

Many desert or desert-like habitats do not burn very frequently, and plant communities in such areas are generally not fire “adapted,” and may be severely damaged or eliminated by fire. Cacti, for example, often experience delayed mortality following fire, and should generally not be burned if they are to be maintained in the plant community. *In situ* burning of desert vegetation might not be advisable in many cases, although areas devoid of vegetation, such as in open spaces between individual plants or in dry channels of intermittent streambeds, may present good opportunities for *in situ* burning. It should be noted, however, that fire can alter or destroy surface crusts which are an important component of desert soils, causing unforeseen impacts, even in unvegetated areas.

CONCLUSIONS

In situ burning can be a valuable oil spill cleanup tool in inland and upland environments, particularly under certain conditions. *In situ* burning can be considered when oil needs to be removed quickly to prevent the spread of contamination or further environmental damage. *In situ* burning also may be appropriate when spill locations are remote or have restricted access due to terrain, weather conditions, or other factors. *In situ* burning also appears to be an important alternative when other cleanup options prove ineffective or threaten to be more harmful to the environment.

The *in situ* burning case histories examined outline the state of the practice concerning where and when *in situ* burning is feasible and environmentally acceptable. *In situ* burning is clearly suited towards use in certain environmental settings and habitats, but not others. Some wetland types (especially marshes), other open grassy areas (e.g., fields, agricultural land), and unvegetated sites present good opportunities for *in situ* burning. Other sites, such as most forests and populated areas, are less suitable. Conditions that influence the appropriateness of *in situ* burning in terms of environmental damage include such things as water level and soil type, the potential for erosion, and factors relating to vegetation condition and response in the spill/burn area. In terms of vegetation, plant type (herbaceous vs. woody), seasonality (dormant vs. growing season), and the potential impacts of remaining oil residue on revegetation, stand out as important considerations that should be evaluated for each spill.

Given the available case-history information, the overall knowledge and information base concerning *in situ* burning of inland an upland environments is still limited. To help add to this knowledge base, summary information from the fields of fire ecology and prescribed burning (in the absence of oil) is a valuable tool, increasing the information available to oil spill responders concerning the potential responses of different habitat types and plant species to *in situ* burning.

Similar to the case histories, the fire ecology and prescribed burning literature indicated that herbaceous wetlands and open grassland communities are the most obvious areas where *in situ* burning may be feasible and environmentally acceptable. However, not all terrestrial grassland communities and species are good candidates for *in situ* burning. Important differences in growth form and life-history, as well season, precipitation patterns, substrate/soil type, fuel load, and fire history can make some grassland habitats more appropriate than others for burning. Also, surprisingly, a wide variety of habitats dominated by woody shrubs, and even some tree species, could potentially support *in situ* burning without undue environmental damage.

The use of information gathered from the fire ecology and effects literature comes with a strong disclaimer. Fire sensitive vegetation types where *in situ* burning should definitely not be used can be clearly identified, however, the appropriateness of burning of oil in plant communities described as fire tolerant or resistant is largely untested. Due to the complexity of fire science and prescribed burning, and fire ecology and environmental effects in particular, we suggest that prescribed fire practitioners be consulted when *in situ* burning is planned, to provide valuable knowledge and experience not likely possessed by spill responders. Furthermore, there are several modeling systems developed by the U.S. Forest Service and others that can be used to predict fire behavior and control, smoke production, fire effects, etc. For more information on fire management models and tools, consult "Fire Management Tools *Online*"; the URL is http://www.fire.org/perl/tools.cgi.

Finally, because relatively few case histories were available, and information borrowed from the fire ecology and prescribed burning literature is largely untested in terms of "adding oil," we strongly suggest that all future applications of *in situ* burning be thoroughly documented and the results made available to the response community. Additionally, we recommend that ideas generated by this and other studies be examined both experimentally and during spills of opportunity where *in situ* burns are employed or tested. Efforts in the past have focused on monitoring air quality during burns. Monitoring of vegetation and substrate effects has been inadequate. It is suggested that simple pre- and post-burn ecological monitoring programs be developed as part of the pre-planning for the use of *in situ* burning, in order to generate information that can better support future decisions on when *in situ* burning is a suitable response option.

REFERENCES

1. Mendelssohn, I. A., Hester, M. W. and Pahl, J. W. Environmental effects and effectiveness of *in situ* burning in wetlands: considerations for oil spill cleanup. Louisiana Oil Spill Coordinator's Office, Louisiana Applied Oil Spill Research and Development Program, Baton Rouge, LA, 57 pp., 1995.

2. S.L. Ross Environmental Research Ltd. and Peter Devenis and Associates. Literature review on *in situ* burning of oil in wetlands. The *In situ* Marsh Burn Working Group, Calgary, Alberta, Canada, 73 p., 1996.

3. Dahlin, J. A., Zengel, S., Headley, C. and Michel, J. Compilation and review of data on the environmental effects of *in situ* burning of inland and upland oil spills. American Petroleum Institute, Washington, D.C., 1998.

4. Wright, H. A. and Bailey, A. W. Fire ecology, United States and Southern Canada. John Wiley and Sons, Inc., New York, NY, 501 p., 1982.

5. Cerulean, S. I. and Engstrom, R. T. Fire in wetlands, a management perspective. In: Proceedings of the 19th Tall Timbers Fire Ecology Conference, Tallahassee, FL, 171 p. 1995.

6. Whelan, R.J. *The ecology of fire*. Cambridge University Press, Cambridge, UK, 346 p., 1995.

7. Fischer, W. C. The Fire Effects Information System database. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT, 1992.

Table 1: Fire effects summary for Big bluestem, *Andropogon gerardii*.

Common Name	**Growth Form**	**Fire Tolerant ? (“Adaptations”)**	***In situ* Burn Potential**	**Comments and Considerations**
Big bluestem	Grass	Yes; fire adapted (rhizome 2.5 cm to 5 cm below soil surface, fire plays role in maintaining plant community)	High	Grassland fires are low intensity and fast moving; high intensity and/or slow fires may be more damaging; burning in late spring when dormant is best, resulting in vigorous new growth and increase in flower stalks; summer growing season burns most damaging, regrowth is slower and less vigorous; drought conditions cause reduced growth after burning; similar effects can be seen in areas with naturally low precipitation

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The Minerals Management Service (MMS), U.S. Department of Interior, is designated as the lead agency for *in situ* burn research in the Oil Pollution Research and Technology Plan prepared under the authority of Title VII of the Oil Pollution Act of 1990 (OPA-90). In response to MMS's continuing effort to ensure the relevance of their research program to the needs of the user community, and as a result of widespread preapproval of *in situ* burning and advances in the technology, MMS hosted this workshop to update the state of knowledge and the research needs of the user community. The goals of the *In Situ* Burning of Oil Spills Workshop were: 1) To present the state of knowledge to decision makers from local, state and federal agencies, responders, environmentalists, academia, industry and the user community, and 2) To prioritize research and information needs to support decisions on the use of *in situ* burning of oil spills. Papers were presented reviewing the state of *in situ* burning of oil spills technology. The workshop attendees were invited to participate in two breakout discussion panels to develop research needs. One focused on environmental and human health issues and the other on operations issues. This Proceedings is the official transmittal of the workshop presentations and the research needs developed by the panels.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)

crude oil, environmental effects, fire research, fire models, *in situ* burning, human beings, oil spills, operational hazards

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