IN-SITU BURNING RESEARCH RECOMMENDATIONS ARISING FROM COMPREHENSIVE REVIEW

by

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Introduction

A comprehensive report was recently completed for the Marine Spill Response Corporation (MSRC) entitled "The Science, Technology, and Effects of Controlled Burning of Oil Spills at Sea" (Buist et al. 1994). The study serves to summarize and evaluate all knowledge in the area of in-situ burning as a countermeasures technique for oil spills at sea. Two subjects of concern in the study, the environmental impacts of in-situ burning and the effects on human health and safety, are summarized in other papers in these proceedings (Westphal 1994, Campbell 1994).

The MSRC report provides extensive documentation to support the view that in-situ burning of marine oil spills is a promising countermeasures technique that can be used on selected spills with effectiveness and safety. It thus recommends that a major effort be initiated to incorporate in-situ burning programs in existing contingency plans and to educate and train both operators and regulators accordingly. The report makes strong ecological and human-health arguments for considering in-situ burning under most marine spill situations (Westphal 1994, Campbell 1994) but states that the major constraint to the routine use of the countermeasure remains our lack of operational experience and lack of knowledge regarding spill situations where burning can be considered feasible, practical and effective. For example, we remain uncertain about the effects of emulsification on ignition and burning efficiency and remedies for these effects, about the practicalities and efficiencies of uncontained oil spill burning, about the cost-benefits of using smoke suppressors such as ferrocene, and about other important questions. One of the objectives of the MSRC report was to identify and discuss all of the major areas of knowledge and technology that should be pursued to advance the safe and effective use of in-situ burning for dealing with marine oil spills. This paper summarizes the report's findings in this area. We begin with an identification of information gaps. This is followed by a compilation of fifty-two specific research and development ideas that have been proposed in the MSRC study, in previous studies, and in various meetings of researchers over the past five years. Fourteen of the ideas selected by the study team as being the most important are then presented in further detail. Not addressed are the problem of

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oil spilled under or on a complete ice cover, and burning or incineration techniques used for dealing with the products of an offshore recovery or shoreline cleanup program. These areas were not covered in the MSRC study.

Information Gaps

There are two categories of research at issue. The first relates to environmental and regulatory concerns that currently limit the acceptance of in-situ burning as a first-line spill response method. The second relates to technological or operational concerns regarding the feasibility of burning marine oil spills under a range of spill and environmental conditions.

Environmental and Regulatory Concerns: The primary constraint to the use of in-situ burning as an operational tool is concern over the impacts of the byproducts of burning on people and the environment. Until recently, few data existed on the constituents of the smoke and their concentrations, the chemicals of concern in the residue, and the thermal effects of in-situ burning on the underlying water column. The two large offshore burns of contained crude oil that were conducted off Newfoundland in 1993 were the culmination of a multi-year, multi-million dollar research program on these subjects (Fingas 1994 - these proceedings). It is believed that the results of this offshore study will do much to fill major data gaps in the three areas mentioned. Nonetheless, regulatory acceptance of in-situ burning will likely continue to be a problem because of concerns over the human health implications of burning. This subject area thus forms the basis for several of the R&D recommendations identified in this paper. Another regulatory issue that limits in-situ burning as a response tool is the concept that in-situ burning is a second-tier response tool (i.e., skimming first, then burning). Since there is a "window-of-opportunity" for burning that closes after about a day or less, its relegation to a second-tier response can completely negate its effectiveness. Legal, safety and insurance issues associated with in-situ burning, especially near a stricken vessel, are also key limitations on its use as a response tool. These issues are also included in the list of projects identified for future consideration.

Technological and Operational Concerns: The greatest technological constraint to in-situ burning is emulsification. With present-day technology, even thin and highly evaporated oil slicks can be contained, thickened and burned using fire containment booms; however, if the oil emulsifies beyond a certain limit, ignition is not possible. Other external limitations also exist, such as wind speed, sea state, visibility and currents. All of these combine to define a spill-specific "window-of-opportunity" for in-situ burning.

The appropriate equipment that should be deployed on-site for in-situ burning also requires research. The limitations and capabilities of igniters and fire containment booms must be fully researched and understood before in-situ burning can be used with confidence. Finally, there are a number of operational issues that remain unanswered, such as how to coordinate a multi-approach response involving burning, dispersing and skimming so as to maximize oil removal and minimize environmental impact.

Previously Identified R&D Ideas

This section lists specific research and development ideas that have been proposed over the past five years. These were taken from proceedings of the following symposia and workshops:

Alaska Arctic Offshore Oil Spill Response Technology Workshop — Nov/Dec 1988 (Jason 1989)

Workshop to Establish Canadian Marine Oil Spill Research and Development Priorities — March 1990 (Ross and Potter 1990)

Research Needed to Respond to Oil Spills in Ice-Infested Waters — Findings and Recommendations of the U.S. Arctic Research Commission — May 1992 (Anonymous 1992)

First International Oil Spill R&D forum — June 1992 (TMS 1992)

In addition, papers presented at oil spill conferences dealing with the R&D activities of various organization were reviewed, including those of MSRC (MSRC 1991, Engelhardt 1992 and 1993), MMS (Tennyson 1993), Environment Canada (Fingas 1992), NIST (Evans 1992) and USCG (Jensen and Tebeau 1991). Study team members also contributed their own ideas, as documented in the full MSRC report (Buist et al. 1994).

As a result of the review, 52 R&D ideas evolved. These are listed in Table 1. The ideas have been sorted into five categories pertaining to:

- processes,
- technology,
- field trials,
- operational, and
- environmental and human health.

The ideas are not presented in any particular order.

Compendium of In-Situ Burning R&D Ideas

Category	Idea	Description	Sources
Processes	1. Effects of Emulsification	• continue R&D to ascertain the processes occurring during burning of w/o emulsions and the limitations imposed by emulsification on ignitability, flame spreading and burning of emulsions, including thermal aspects.	Jason 1989 USARC 1992 Ross & Potter 1990 Evans 1992 Fingas 1992 Tennyson 1992 Engelhardt 1992, 1993 MSRC 1991 Buist et al. 1994
	2. Effects of Currents and Waves	• study the effects of currents and waves on in-situ burning.	Ross & Potter 1990 USARC 1992 IOSR & DF 1992 MSRC 1991 Buist et al. 1994
	3. Effects of Oil Types and Properties	• study the effects of oil type and properties on the basic processes of in-situ burning.	USARC 1992 Tennyson 1992
	4. Burning in Broken Ice	• investigate the effects of broken ice on in-situ burning of oil.	Jason 1989 Ross & Potter 1990
	5. Uncontained Burning	• continue research and modeling efforts regarding the ignition and burning of uncontained oil slicks on water.	Ross & Potter 1990 Buist et al. 1994
	6. Scaling Effects	• conduct test burns with a range of fire sizes and oil types to measure effects of scale on various burn processes.	Jason 1989 Tennyson 1992
	7. Burning Oil on Mudflats	• investigate the feasibility of burning oil on mudflats, where no other countermeasures can be used.	Ross & Potter 1990 Engelhardt 1992
	8. Burning at/or near Shorelines	• evaluate the possibilities for burning oil at/near certain shorelines, e.g., marsh.	Fingas 1992
	9. Flame Spreading	• study the effects of wind, temperature, oil type, thickness, etc. on flame spreading rates over oil slicks and develop suitable models.	Buist et al. 1994

Category	Idea	Description	Sources
Technology	10. Smoke Reduction	• continue the development of technologies/additives to reduce/eliminate smoke produced by in-situ burning.	Jason 1989 USARC 1992 Engelhardt 1993
	11. Break and Burn	• investigate techniques for reducing emulsification in slicks to permit ignition and burning and extend "window-of-opportunity", including emulsion breakers, anti-foaming agents, ignition promoters and combustion promoters.	Ross & Potter 1990 IOSR & DF 1992 Engelhardt 1993 Buist et al. 1994
	12. Novel Methods to Enhance In-Situ Burning	• study ways to increase burn rates and efficiencies, including combustion air increases, instigation of vigorous burning, radiation reflectors, wire mesh media in boom pockets, water injection and combustion promoters.	Jason 1989 Ross & Potter 1990 IOSR & DF 1992
	13. Capabilities and Limitations of Existing Igniters	• develop a quantitative description of the capabilities and limitations of existing igniter technology as a function of weather, sea state, oil type and emulsification variables.	USARC 1992 Buist et al. 1994
	14. New Fire Proof Boom Designs	• develop new fire resistant boom technology to improve efficiency and enable operations in higher sea states.	IOSR & DF 1992 Engelhardt 1993 Buist et al. 1994
	15. Standardized Testing of Fire Proof Booms	• quantify the capabilities and limitations of existing fire booms in salt water wave tanks/basins, with fire using standardized test methods.	Ross & Potter 1990 Buist et al. 1994

Category	Idea	Description	Sources
Technology cont'd	16. Igniter Improvements	• continue research into improving the capabilities and reducing the limitations of the Helitorch by studying additives and alternate fuels.	Buist et al. 1994
	17. New Igniter Concepts	• research novel igniter techniques.	USARC 1992
	18. Residue recovery	• develop/test potential methods for the recovery at sea of burn residue.	Jason 1989 Ross & Potter 1990 USARC 1992
Field Trials	19. Offshore Fire Proof Boom Trials	• verify mesoscale work on efficiency and develop protocols; sufficient number of trials to determine viability under variable weather and sea conditions; quantify scale rules.	Jason 1989 Ross & Potter 1990 USARC 1992 Evans 1992 Tennyson 1992 IOSR & DF 1992
	20. Ignition and Burning of Emulsions	• research the ignition and burning of emulsions of varying water content and weathering to assess capabilities and limitations and scaling rules.	Jason 1989 Ross & Potter 1990 Buist et al. 1994
	21. Uncontained Burning	• evaluate the efficacy of burning uncontained oil in the 1 to 10 m^3 size range.	Ross & Potter 1990 Buist et al. 1994
	22. Burning in Broken Ice	• conduct a burn in broken ice conditions to determine the efficacy of the technique.	Jason 1989 Ross & Potter 1990
	23. Igniter Tests	• evaluate ignition devices.	Ross & Potter 1990

Category	Idea	Description	Sources
Operational	24. Equipment Deployment Exercises	• demonstrate techniques and train end users in the methods employed in in-situ burning; refine procedures; determine limitations imposed by weather and sea conditions.	USARC 1992 IOSR & DF 1992 Engelhardt 1993 Buist et al. 1994
	25. Control of Offshore In-Situ Burning	• research, develop and/or test techniques of controlling offshore in-situ burns; as a function of pool size; extinguishment techniques.	Engelhardt 1993 Buist et al. 1994
	26. Comparison of Trade-Offs with other Response Techniques	• research, document and compare the trade-offs between mechanical, chemical and burning countermeasures.	USARC 1992
	27. Safety Issues	• study the safety issues associated with in-situ burning; develop protocols and procedures for safe operations; institute loss management techniques.	Jason 1989 Ross & Potter 1990 USCG 1991 Buist et al. 1994
	28. Regulatory and Public Education Programs	• develop techniques to inform and educate regulators and the public as to the capabilities and limitations and trade-offs associated with in-situ burning; include net environmental benefits analysis and safety aspects.	Jason 1989 Ross & Potter 1990 USCG 1991 Buist et al. 1994
	29. Practicality Assessment	• assess the practicality of various burn scenarios vis a vis operational windows; incorporate response time, personnel and equipment availability, staging logistics, oil behavior, etc. for a range of weather and sea conditions.	Jason 1989

Category	Idea	Description	Sources
Operational cont'd	30. Ignition Procedures	• develop procedures for ignition of slicks on water (or ice) in a range of situations; include oil type, weather, sea state, logistics, etc., as variables.	Buist et al. 1994
	31. Large Spill Burning	• develop procedures for employing in-situ burning at large spills; include interactions with other response operations.	Engelhardt 1993
	32. Protocols and Procedures	• develop standardized protocols and procedures for the implementation of in-situ burning offshore.	USCG 1991
	33. Legal, Environmental and Safety Issues	• define the legal, environmental and safety issues associated with controlled in-situ burning and develop decision protocol for the O.S.C.	USCG 1991
	34. Uncontained Burn Issues	• as 33 above, but for the situation of ignition, and burning uncontained slicks.	Buist et al. 1994
	35. Decision Making Aids for Extinguishing Vessel Fires	• develop decision-making aids for the case of extinguishing an already-burning vessel; incorporate legal, insurance and environmental trade-off aspects.	Buist et al. 1994
	36. Helicopter Safety	• assess the safety of operating helicopters in the vicinity of burning operations.	Ross & Potter 1990

Category	Idea	Description	Sources
Environmental Issues	37. Effects of Low Temperature and Winds	• assess the effects of emissions at low temperatures and a range of wind speeds.	USARC 1992
	38. Develop Smoke Plume Models	• write and test better computer models to predict air pollution impacts; make existing models simpler for use on personal computers.	Ross & Potter 1990 Fingas 1992 IOSR & DF 1992
	39. Thermal Effects on Water Column	• quantify the thermal effects of in-situ burning on the water column; create mathematical models to predict effects in various situations.	Buist et al. 1994
	40. Burn-of-Opportunity Research	• at accidental oil fires, measure particulate fallout downwind and attempt to measure environmental impacts.	Fingas 1992 Buist et al. 1994
	41. PAH and Metals	• further study of PAH's and metals.	Fingas 1992 Buist et al. 1994
	42. Residue Studies	• study of changes to residue.	Fingas 1992 Buist et al. 1994
	43. Aldehydes and Ketones	• study of aldehydes and ketones.	Fingas 1992 Buist et al. 1994
	44. Particulates and Residue Toxicology	• study the toxicology of particulates and residue.	Fingas 1992 Buist et al. 1994
	45. Emission Assessment Techniques	• develop rapid techniques for assessing emissions in real and trial spills.	Fingas 1992 Buist et al. 1994
	46. Plume Measurement Techniques	• develop rapid plume measurement techniques.	Fingas 1992 Buist et al. 1994
	47. Flux Gases	• assess the flux gases from burns.	Fingas 1992 Buist et al. 1994
	48. Impact Assessment Protocols	• develop impact assessment protocols for spills of opportunity.	Fingas 1992 Buist et al. 1994
	49. Monitoring Techniques	• develop monitoring techniques for in-situ burn response implementation.	Fingas 1992 Buist et al. 1994
	50. Effects of Residue Sinking	• determine the causes, conditions and environmental effects of in-situ burn residue sinking.	Buist et al. 1994

Category	Idea	Description	Sources
Environmental Issues cont'd	51. Burn Consideration Zones	• use present air quality models to develop pre-approved zones for coastal areas.	Buist et al. 1994
	52. Burn Risk Model	• develop a fast, transportable, field-simplified risk assessment model for burn screening.	Buist et al. 1994

Recommendations for Future R&D

Each member of the study team separately selected his personal "top ten" ideas from the 52 listed in Table 1. All "top ten" lists were then consolidated into one list of fourteen R&D areas. Several of these areas incorporate more than one R&D idea with a common theme (i.e., uncontained burning research is included in ideas #5, 21 and 34 in Table 1). Each recommended R&D area is now briefly described; the corresponding R&D idea(s) from Table 1 are given for each area. The recommended R&D areas are not listed in any particular order.

Effects of Emulsification (Table 1, #1). Although progress has been made recently in understanding the basic processes involved with in-situ burning of emulsions, more needs to be done to quantify the limitations it imposes on:

- ignitability,
- flame spreading,
- burn efficiency, and
- burn rate.

Particular aspects requiring further study are:

- scaling effects,
- parent oil effects,
- sea state effects, and
- the development of a simple "screening" test for a particular oil.

Uncontained Burning (Table 1, #'s 5, 21 and 34). Preliminary studies in the mid-1980s (S.L. Ross and Energetex 1986) indicate that ignition of thick, fresh crude oil slicks that are not contained in booms can result in high removal efficiencies because the air drawn into the fire keeps the slick from spreading. Further research is recommended to:

- determine viability at larger scales,
- explore the capabilities and limitations of the technique,

- validate mathematical models, and
- address the legal, environmental and safety issues associated with uncontained burns.

Flame Spreading (#9). The achievement of high overall removal efficiencies using in-situ burning requires that the flames spread from the ignition source to cover the greatest possible area of the slick. Flame spreading may very well be the limiting factor governing burning practicability. Little work has been done on flame spreading over oil slicks, particularly at larger scales in the field. Research is needed in the areas of:

- effects of oil type and weathering,
- effects of slick thickness,
- environmental and sea state influences, and
- flame spreading promoters or primers.

Break and Burn (#11). This research area offers potential to extend the "window-of-opportunity" for in-situ burning. Emulsion breakers can be applied aerially to an emulsified slick to reduce its water content (e.g., Lunel and Lewis 1993) and perhaps render it ignitable. Some preliminary small-scale testing has been undertaken (e.g., Guenette et al. 1994, this conference) but much more is required. Research (both lab-scale and field-scale) is recommended in the areas of:

- scaling emulsion breaker burn testing,
- potential for anti-foaming agents,
- application of ignition and flame spreading promoters, and
- operational aspects.

Fire Control and Safety Issues (#'s 25 and 27). The fire control part of this R&D area relates specifically to researching, developing and/or testing methods that can be used offshore to:

- extinguish an already burning oil slick or portion thereof (either contained or uncontained), and
- positively control the spread of fire over slicks (particularly near the source of the slick).

The safety portion of this R&D area relates to developing and testing procedures for safe, controlled in-situ burning offshore (including fire control). Key areas would involve ignition safety, personnel protection and flame and heat hazards.

Fire-Proof Boom Studies (#'s 14 and 15). Many varieties of fire-proof or fire-resistant containment booms are commercially available; each has its capabilities and limitations. Fabric-based booms are relatively lightweight and flexible but may only survive a few hours of exposure to flames, particularly in waves; metallic booms are available that offer excellent fire resistance, but these tend to be heavier, more cumbersome and less flexible than fabric booms. A standardized test protocol for fire proof booms needs to be developed (ASTM Committee F-20 is addressing this) and a suitable test facility needs to be located or developed. Concurrently, research and development of new fire proof boom designs should continue with the objective of developing a lightweight, easy-to-handle, long-life, high-seas product.

Burn-of-Opportunity (#40). One obvious technique for collecting smoke plume data for large oil fires is to respond to accidental oil fires-of-opportunity (such as tank farm fires, tanker fires, etc.) and measure key smoke parameters and any environmental impacts, including human health impacts. This would avoid the costs and regulatory problems of mounting a large experimental burn program. This program would entail developing a rapid response unit (both monitoring equipment and personnel) properly equipped to take advantage of accidental oil fires.

Smoke Reduction (#10). The smoke plume from an in-situ burn is considered a major constraint to the use of the technique as an operational tool. If the smoke could be eliminated, much of the resistance to the use of burning would be reduced. Several studies of the use of Ferrocene and its derivatives as a smoke suppressant have shown promising results (e.g., Guenette et al. 1994, this conference; Mitchell and Moir 1992). Continued research on cost-effective additives and application technologies is warranted.

Igniter Tests and Improvements (#'s 13, 16 and 23). Some commercially available igniter systems have been extensively tested and others have undergone only limited testing. In order to select the proper igniter for a given spill, it is necessary to develop a standardized series of tests for igniter systems that will quantify their effectiveness as a function of oil type, and weathering, (particularly emulsification), sea state, and environmental conditions. The ASTM F20 committee is planning to consider this in the future.

It is also recommended that the research into extending the capabilities of gelled-gasoline igniter systems, exemplified by the Heli-torch, be continued. The use of alternative fuels (Bech et al. 1992) and additives, including emulsion breakers and smoke suppressants (Guenette et al. 1994, this conference), shows promise in lab and small-scale testing as a means of expanding the applicability of this type of igniter system to emulsions. Research into other types of additives, delivery system tests and larger scale testing are all recommended.

Residue Sinking (#50). One existing constraint on the use of in-situ burning is the concern that the residue remaining on the water after the burn will sink and contaminate the sea bottom. Much research and field testing has indicated that this is not likely for most oils; however, some heavy crudes that have burned at sea are reported to have sunk (Turbini et al. 1993, Moller 1992). Research on the likelihood of burn residue from fires of heavy (i.e., high density) crudes sinking, conditions that favor sinking and the potential environmental effects is recommended.

Practicality Assessment (#29). A study is needed to assess the practicality of in-situ burning operations for a range of spill types, spill sizes and environments. Using a scenario approach and realistic response capabilities, in-situ burning would be applied to a large number of spill scenarios and its likely effectiveness in removing oil would be estimated using known mathematical techniques. The equipment requirements, response times, logistical support necessary, cost and removal efficiency would be compared critically with conventional containment and response and dispersant application operations.

Protocols and Procedures for Contained Burning (#32). Some regions of North America (notably Alaska and EPA Region VI - Louisiana and Texas) have made considerable progress in developing pre-approval protocols for offshore in-situ burning, and some response organizations have state-of-the-art in-situ burning response plans in place. Many other areas and response organizations are not as advanced, so continued efforts to develop standardized protocols and procedures for contained in-situ burning (using booms) is recommended. Without clear guidelines on when and how to implement an in-situ burning operation, its operational use is unlikely. The ASTM F20 committee is addressing some aspects of this area.

Legal, Environmental and Safety Issues (#33). In order to implement an in-situ burning operation, an On-Scene Commander (OSC) needs to consider the legal, environmental and safety ramifications of the planned burn(s). It is recommended that these be clearly defined and documented and that an easy-to-use decision protocol for the OSC be developed. Some jurisdictions in the U.S. (e.g., Alaska, EPA Region VI) have checklist-type burn application forms that address these issues; these would form an excellent framework for other jurisdictions.

Regulatory and Public Eduction Programs (#28). One key stumbling block to the operational use of in-situ burning is the unconsidered fear of the effects of in-situ burning by the general public, special interest groups and some regulatory agencies. It is recommended that methods be devised for educating concerned persons about the capabilities and limitations of burning, potential impacts of the smoke, safety aspects and net environmental benefits.

Conclusion

On the basis of a comprehensive review of in-situ burning as a countermeasures technique for oil spills at sea, and a review of proceedings from past meetings of experts, a list of fourteen ideas for top R&D consideration has been developed. The list should be considered preliminary and open for discussion. The aim in the end is to develop a coordinated R&D program for in-situ burning that leads to the regular acceptance and use of the technique in the overall interests of protecting the environment and human health and safety.

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