Technology Assessment and Concept Evaluation for Alternative Approaches to In-Situ Burning of Oil Spills in the Marine Environment

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Executive Summary

The objective of this study is 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, that continues to discharge oil. 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 are investigated. The first is the use of a towable oil spill burning device 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.

A general assessment is made of the characteristics of spills where these applications might be encountered. This assessment includes 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 identified, design scenarios are developed which are representative of the offshore and nearshore conditions where the alternative approaches to in-situ burning may be effectively applied.

Several conceptual systems for burning in the offshore, continuous-source, and shallow-water applications are proposed. These include:

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 oil flaring burner
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

Development of the conceptual systems focuses on integrating proven or potentially viable technologies. The emphasis is on simplicity of design (a minimum amount of complexity and

machinery), and ease of transport and deployment. This improves the system reliability and availability for response in distant locations.

Having proposed these several conceptual designs, the feasibility of building, assembling and modifying the necessary platforms and equipment to form a complete system is investigated in detail. Anticipated performance in terms of oil burning capacity, stability, seakeeping, and durability are investigated. System cost and the ability to meet inspection and certification criteria are also considered. The engineering feasibility assessment is largely based on first-order calculations, current engineering practice, and past experience with such systems and equipment. As the systems are only described at a conceptual level, cost and construction time projections represent order of magnitude estimates. In addition, the transportation, deployment and operational support requirements required in implementing the alternative approaches in an actual spill situation are explored. Transport and deployment logistics requirements, operations monitoring and control procedures, occupational and environmental safety considerations, and policy constraints are analyzed at a strategic level. Having completed the engineering and operational analysis, the alternative approaches are summarized in terms of the basic concepts and designs proposed (including equipment and procedures), and a preliminary assessment made of the overall feasibility of producing such a system. Advantages and constraints are summarized, and second-level conceptual drawings presented.

Having further specified the characteristics of each conceptual design, a hindcast analysis is 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 systems if they are carried forward for further development and testing. In addition, the results of the analysis are reviewed by a panel of government and industry experts in oil spill response technology and operations, and particularly in-situ burning, to solicit guidance on the viability of these concepts and issues that still need to be addressed. Based on the preceeding analysis and the comments and suggestions of the panel, recommendations for further research, development, testing and evaluation of specific concepts are presented. The conclusions and recommendations for each concept are summarized as follows:

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 $1M or more. Potential application is limited which will make the cost of maintenance and training prohibitive. Further development of this concept is not recommended.

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. A common disadvantage is the need for pre-staging near the potential spill sites and their higher cost. As with Concept I, the need for systems of this size is somewhat infrequent, such that the cost of construction and maintenance appears prohibitive. However, 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 (Concept IIB) 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 - 5000 BPD) 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 is also attractive. Because the device is smaller and more maneuverable, it can be actively towed though an oil slick. Rapid conversion to a conventional skimming unit may be feasible. Accordingly, it is recommended that this concept be explored further as a possible alternative for dealing with larger spills from platforms and vessels.

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. In addition, the hindcast analysis in Section 9.0 indicates that the occurrence of spills where such a device might be employed is less than expected, making the cost and logistics involved in constructing such a device questionable. Accordingly, there is no reason to pursue this concept further.

Concept V - This concept is simple, inexpensive and reliable and can be implemented using readily available materials. Refinements to the barrier and anchoring scheme will increase ease of deployment. This is a simple design and fabrication project and does not require further R&D. It should also be noted that the barrier is useful for shallow water containment even when burning is not permitted or not desirable.

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Frequently Used Acronyms and Abbreviations

ACP	**Area Contingency Plan**
AFFF	**Aqueous Film Forming Foam**
ASTM	**American Society of Testing & Materials**
BPD	**Barrels per day**
EPA	**Environmental Protection Agency**
ISB	**In-Situ Burning**
LOA	**Length Overall**
MMS	**Minerals Management Service**
MSO	**(U.S. Coast Guard) Marine Safety Office**
NM	**Nautical Mile**
NOAA	**National Oceanic and Atmospheric Administration**
NRT	**National Response Team**
USCG	**U. S. Coast Guard**

1.0 Background and Objective

In-situ burning of oil has been considered as an oil spill response technique since the TORREY CANYON spill in 1967 demonstrated the threat posed by major oil spills at sea. Since then, a number of spills have occurred where burning became an effective de facto response technique for removing oil from the water through accidental explosion and ignition at the source (e.g., BURMAH AGATE spill, MEGA BORG spill, HAVEN spill and others). In other spills, in-situ burning has been undertaken as a deliberate countermeasure with varying degrees of success, particularly in cases where mechanical recovery operations were not feasible, or clearly inadequate in dealing with the volume of oil spilled. A summary of past experiences with burning of oil spills is provided in a comprehensive review of the theory, technology and operations involved in in-situ burning published by the Marine Spill Response Corporation (Buist *et al.*, 1994a).

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. This response technique was used in the initial stages of the EXXON VALDEZ response in March of 1989 during which 15,000 gallons of Prudhoe Bay Crude were effectively burned using a fire-resistant boom as a containment and incineration device. Subsequent burn operations were precluded by a storm on the third day of the spill which emulsified the oil making it unburnable.

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 in the years following 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 (Fingas *et al.*, 1995). 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. As a result, there is growing acceptance of in-situ burning as a standard countermeasure, with Regional Response Teams and Area Committees integrating it into their response protocols and contingency plans.

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, and will remain serviceable for only a few hours to perhaps a day (Environment Canada, 1997). Further technology development efforts are proceeding to improve the durability of fire-resistant booms and to establish an ASTM test procedure for fire-resistant booms which will provide a benchmark for future boom performance. More recent burning tests have been conducted to determine the durability of existing booms and verify the ASTM standard (McCourt *et. al.*, 1997). These tests have shown that the service life of boom sections in the apex of the boom during burning operations (those exposed to the higher levels of mechanical and thermal stress) remains on the order of several hours (perhaps 6-10 hours). This suggests that there may be an upper limit to the duration of a burn operation (on the order of 12 hours) after which the boom must be refurbished and redeployed.

With this limitation in mind, it is prudent to take another look at the concept of burning as an oil spill response tool and how it can be implemented under the full range of oil spill scenarios that are possible. This is particularly appropriate as oil spill response technology efforts are often driven by the technologies employed and the success or failure in responding to the last major spill that caused extensive environmental damage capturing the nation's attention (often described as catastrophic spills). This may result in intensive efforts to develop technologies to respond to the "last big spill" at the expense of investigating methods to respond to scenarios that are equally as likely and potentially as damaging in the future.

The objective of this study is to provide such 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 or possibly a grounded or sunken tanker or barge, that continues to discharge oil. 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 will be 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 will be researched and analyzed to determine relevant technologies, viable concepts, engineering design feasibility, and operational requirements and constraints. The goal is to identify viable concepts (systems, equipment and procedures) that can be carried forward for further research, development, test and evaluation.

2.0 Methodology

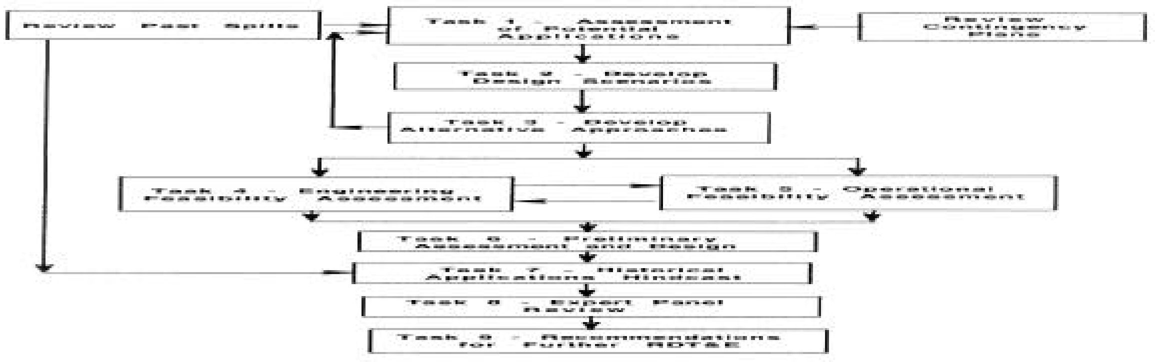
This study is designed to be a strategic, first-order assessment of the engineering and operational feasibility of various concepts (devices, systems and procedures) for addressing the continuous, offshore spill and restricted shallow-water alternative applications of burning as described in Section 1.0. The overall methodology for the analysis is shown in Figure 2-1.

The first task in the study is a general assessment of the characteristics of spills where these applications might be encountered. This assessment includes 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. Each spill situation where these applications might have been employed in the past, or could be employed in the future, is described according to spill size and spill rate, type of oil, location and environmental conditions, and overall success achieved or anticipated in dealing with the spill.

Based on the actual and expected spill situations identified in Task 1, design scenarios are developed which are representative of the offshore and nearshore conditions where the alternative approaches to in-situ burning may be effectively applied (Task 2). For each general scenario, design parameters are proposed including 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).

Task 3 involves the development of several conceptual systems for burning in the offshore, continuous source, and shallow-water applications. This includes proposing the devices, deployment techniques and operating procedures that could be used as alternatives to the fire-resistant boom approach. Insight on how the conceptual systems could be configured comes largely from previous oil spill burning technology development and testing efforts (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. These technologies have been investigated in detail over the past twenty years and are well-documented in the technical literature. In many cases, full-scale prototype devices were developed, some of which are now available as spill response equipment. The development history of technologies relevant to this study is summarized in Appendix A.

Development of the conceptual systems focuses on integrating some of these proven or potentially viable technologies to address the offshore, continuous source and shallow-water applications. The capacities and configuration of the systems will be dictated by the design scenario parameters developed in Task 2. The emphasis is on simplicity of design (a minimum amount of complexity and machinery) and ease of transport and deployment. This improves the system reliability and availability for response in distant locations.



Task 4 and Task 5 involve a strategic analysis of the engineering and operational considerations for the conceptual systems proposed in Task 3. Task 4 investigates 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 are investigated. System cost and the ability to meet inspection and certification criteria are also considered. The engineering feasibility assessment is largely based on first-order calculations, current engineering practice, and past experience with such systems and equipment. As the systems are only described at a conceptual level, cost and construction time projections represent order of magnitude estimates.

Task 5 involves analyzing 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 are analyzed at a strategic level.

Tasks 4 and 5 are conducted in parallel as shown in Figure 2-1 as engineering design to some extent defines the operational requirements of a system; but in turn, logistics, spill response tactics and procedures, and environmental policy considerations often constrain the engineering design. Thus the two analyses are not independent of each other.

In Task 6, the alternative approaches are summarized in terms of the basic concepts and designs proposed (including equipment and procedures), and a preliminary assessment made of the overall feasibility of producing such a system. Advantages and constraints are summarized, and second-level conceptual drawings presented.

Task 7 incorporates an analysis all too often neglected as oil spill technologists seek to identify, develop and refine oil spill response technologies. This involves a cursory hindcast analysis 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. Task 7 is designed to put the concepts proposed in proper perspective with respect to application.

In Task 8, the results of the analysis are reviewed by a panel of government and industry experts in oil spill response technology and operations, and particularly in-situ burning, to solicit guidance on the viability of these concepts and issues that still need to be addressed. As such, Task 8 constitutes a “reality check” for the study. Recommendations for further research, development, testing and evaluation of specific concepts are presented in Task 9.

3.0 Assessment of Potential Applications

To develop the various concepts that can be employed in the offshore-continuous source and shallow-water applications of burning, it is necessary to understand the general circumstances surrounding such spills, the frequency with which they occur, the specific parameters that relate to the design and construction of the devices and equipment, and the procedures and constraints involved in employing response techniques and equipment. The primary sources of information in this regard are the descriptions of past spill response efforts as documented in the literature, and the scenarios used in developing contingency plans for future spills as required by the Oil Pollution Act of 1990 (OPA 90).

3.1 Review of Past Spills

In investigating the circumstances surrounding past spills, the primary sources of information were the National Oceanic and Atmospheric Administration (NOAA) Spill Histories Summary (NOAA HAZMAT, 1992), and the proceedings of the biennial International Oil Spill Conferences (1969-1997). Other sources include On-Scene Coordinators’ Reports for certain major spills, the NOAA SSC Spill Summaries, and other technical publications such as the Arctic Marine Oilspill Program (AMOP) Proceedings.

With regard to the offshore spills considered, a cursory review of the spill circumstances shows that the platform blowouts are far more likely to present a stationary, high volume, continuous source release than major spills involving vessels. Vessel spills are associated with casualties, often occurring under adverse weather conditions, where the release is instantaneous, or occurs as a series of high volume discharges of short durations, which are quickly spread over a wide area by wind and currents. Accordingly the window of opportunity for effective response is limited to a few hours, or a few days at best. These releases are generally not amenable to using the alternative approaches proposed.

Blowouts and other platform casualties are far more likely to offer a steady-state release over a period of several days and often up to a month, allowing the deployment and operation of burning devices over an extended period of time. As the spill involves fresh crude oil instead of a residual fuel or highly weathered crude, the oil is more likely to be burnable if it can be intercepted near the source (provided it is not emulsified as it enters the water). Because the releases generally continue for periods of several days to several weeks (and in some cases months), there is adequate time to transport and deploy equipment, and conduct burning operations. A summary of the blowout situations, which have presented long-term, continuous high volume discharges is provided in Table 3-1.

In addition to major offshore and vessel spills, several spills were studied which involved discharges of oil into coastal marshes and rivers, in which in-situ burning was used as a countermeasure (either deliberately or accidentally). These included a 2900 bbl light crude oil spill into a marsh near Copano Bay, Texas (Gonzalez and Lugo, 1994); a 1500 bbl JP-5 spill into an ice-covered marsh near New Brunswick, Maine (Eufemia, 1994; NOAA SSC, 1993); and a 400,000 bbl spill of gasoline, light crude and fuel oil into the San Jacinto River resulting from a pipeline break during a flood (NOAA SSC, 1995). These spills, and the shallow-water recovery operations during vessel spills such as the EXXON VALDEZ spill in Prince William Sound (1989) and the Apex Barge spill at Galveston (1989), provided insight for developing the shallow-water marsh and river scenarios.

Table 3-1 Summary of Past Spills Involving Blowouts and Offshore Platform Casualties

Spill Name & Location	Spill Volume	Duration	Spill Rate	Oil Recovered
Chevron Main Pass 41 Gulf of Mexico, 2/10/70	65,000 bbl	48 days	1,000 bbl/day	15,600 bbl
Ekofisk Bravo North Sea, 4/22/77	202,381 bbl	8 days	1,170 bbl/day	None
Hasbah 6 Gulf of Arabia, 10/2/80	100,000 bbl	8 days	11,500 bbl/day	15,000 bbl
IXTOC I, 6/3/79 Bahia de Campeche	3,522,400 bbl	9 months	10,000-30,000 bbl/day	Negligible
Norwuz Oil Field Persian Gulf, 2/10/83	1,904,762 bbl	8 months	1,500 bbl/day	None
Union Oil A-21	100,000 bbl	10 days	5,000 to 30	None

Santa Barbara, 1/28/69			bbl/day	
Shell Platform 26 Gulf of Mexico, 12/01/70	58,640 bbl	5 months	Approx. 1000-20 bbl/day	Dispersants Used
Trinmar Marine Well 327 Venezuela, 8/8/73	36,650 bbl	4 days	Approx 2,000 bbl/day	Dispersants Used
YUM II/Zapoteca	60,000 bbl	50 days	up to 30,000 bbl/day	90% burned at well

3.2 Review of Contingency Plans

In addition to past spill histories, a number of Area Contingency Plans (ACPs) and industry contingency plans (CPs) required under OPA 90 were reviewed to identify scenarios (generally worst case scenarios) that would offer the opportunity for using alternative approaches to burning. A telephone survey was first conducted of Coast Guard Marine Safety Offices (MSOs) and Minerals Management Service (MMS) Regional Offices to locate contingency plan scenarios that involved long-term, continuous, high volume spills. Selected contingency plans were then obtained and analyzed to determine the specific parameters for the scenarios. Three relevant ACP Scenarios and three industry scenarios were identified as described below. The spill parameters for the ACP scenarios are provided in Table 3-2, and for the industry scenarios in Table 3-3. These scenarios are summarized below.

1) MSO Morgan City ACP - Worst Case Discharge, Nearshore/Offshore

At midnight, a catastrophic equipment failure aboard a tanker results in a tanker collision with a manned drilling rig in the vicinity of Southwest Pass, Louisiana, outside of the safety fairway. The collision results in severe hull damage such that most of the cargo is lost (1 million bbl of Kuwait crude). Damage to the drilling rig is such that controlling mechanisms on the wellhead fail resulting in an uncontrollable release (well blowout). The rig continues spilling Louisiana crude at a rate of 60 bbl/hr and releases hydrogen sulfide and methane gas causing potentially toxic levels 10 NM downwind of the spill site. Neither source can be contained over the first 72 hours. Closest point of land is Grand Isle, LA, approximately 49 NM (nautical miles) NNW (North-Northwest) of the spill site. Impact of oil with the Louisiana and Texas shoreline is likely. The spill is considered an “excellent” candidate for in-situ burning

2) MSO New Orleans ACP- Worst Case Discharge, Coastal/Offshore

Essentially the same scenario as in the MSO Morgan City ACP, but the closest point of land is only 4 NM NNE at the Southwest Pass Jetty. The spill is considered an excellent candidate for in-situ burning, as open water recovery methods will be employed, but the expected recovery rate using mechanical means is as little as 4% (40,000 bbl) of the original discharge volume per day.

3) MSO Anchorage ACP - Maximum Most Probable Case

The Granite Point Platform in Trading Bay (located in Cook Inlet, Alaska) experiences a well-blowout resulting in a continuous release of 5,500 bbl/day of Cook Inlet crude oil. Oil released from the platform quickly breaks into stringers oriented with the current. Mechanical recovery of oil in the upper portion of Cook Inlet is extremely difficult and dependent on weather, tides and current; and may be complicated by debris. The Federal On-Scene Coordinator authorizes the use of in-situ burning.

4) Marathon Oil Company CP - Worst Case Discharge

Marathon experiences an uncontrolled blowout off the Louisiana coast (from Ewing Bank Block 873, Platform A) resulting in an initial first day release of 10,259 bbl, followed by a sustained discharge of 9,350 bbl for up to 30 days. Expected landfall of the slick is at Timbalier Island, 57 hours after the spill.

5) Shell Oil Company CP - Worst Case Discharge

Shell Oil Company experiences a catastrophic failure of tension leg platform off the Louisiana coast causing a blowout spill of 30,000 bbl /day for 30 days (with 36,000 bbl/day released in the first 24 hours). The trajectory of the spill is WNW with landfall expected in the vicinity of Terrebone and Lafourche Parishes, Louisiana.

6) Point McIntyre PM-2 Scenario, Prudhoe Bay - Nearshore Blowout to Open Water

The ARCO PM-2 land-based facility at West Dock, Point McIntyre, Prudhoe Bay experiences an uncontrolled blowout resulting in an aerial plume of 12,000 bbl per day . A 20 knot wind blows the oil over the surrounding area with a portion entering Prudhoe Bay. It is early August; the area is ice free. The blowout continues for a period of 15 days. Response includes mechanical recovery and shoreline cleanup; in-situ burning is not attempted.

It is important to note that these scenarios are representative of spills where burning **may be viable** as a response tool. In an actual spill, the particulars of the spill (including the time of year, on-scene weather conditions, the gas/oil ratio of the release, the degree to which the oil is emulsified at the wellhead, etc.) may preclude or constrain the use of burning as a response option.

Table 3-2 Offshore, Continuous Source Spills Described in Area Contingency Plans

Area Contingency Plan	Morgan City	New Orleans	Cook Inlet
Spill Location	Southwest Pass 28-44N, 89-44W	Southwest Pass 28-51N, 89-24W	Cook Inlet 60-57N, 151-19W
Spill Volume	Ship: 1,000,000 bbl Drill Rig 4,320 bbl	Ship: 1,000,000 bbl Drill Rig 4,320 bbl	77,000 bbl
Spill Duration	72 Hrs	72 Hrs	Approx. 2 weeks
Spill Rate	Vessel - rapid loss Rig - 60 bbl/hr	Vessel - rapid loss Rig - 60 bbl/hr	5,500 bbl/day
Spill Cause	Tanker collision with drilling rig	Tanker collision with drilling rig	Wellhead Blowout
Closest Land	40 NM	4 NM	Approx. 5 NM
Season	Summer	Summer	Fall (1 Sept.)
Spill Hazards	Hydrogen sulfide gas up to 10 NM	Hydrogen sulfide gas up to 10 NM	Natural Gas, Fire & Explosion Hazard
Env. Conditions			
- Wind	E-SE, 10-15 kts.	E-S, 10-15 kts.	SW, 15 kts.
- Sea State	7-10 ft.	7-10 ft.	3 ft.
- Current	Not specified	Not specified	1 - 3 knots tidal
- Visibility	1 NM	1 NM	Not specified
- Precipitation	yes, thunderstorms	yes, thunderstorms	Not specified
- Temperature	75 deg. F	75 deg. F	45 deg. F
Spill Trajectory	N-NW, toward Grand Isle, LA	N-W, toward Grand Isle-West Jetty	NE along coast, eventual impact
Expected Oil Recovery	350,000 bbl	350,000 bbl	Not specified
In-Situ Burn Option - Feasible	Viable if sea state decreases	Viable if sea state decreases	Viable, primary approach
- Currently Allowed	Yes	Yes	Yes

Sensitive Resources	Yes	Yes	Yes

Table 3-3 Offshore, Continuous Source Spills Described in Industry Contingency Plans

Contingency Plan	Marathon Oil Co.	Shell Offshore Inc.	Pt. McIntyre
Scenario Type	Worst Case	Worst Case	Worst Case
Spill Location	Gulf of Mexico 28-06N, 90-12W	Gulf of Mexico 28-10N, 89-13W	Pt. McIntyre Prudhoe Bay, AK
Spill Volume	280,000 bbl	900,000 bbl	180,000 bbl
Spill Duration	30 days	30 days	15 days
Spill Rate	9,350 bbl/day	30,000 bbl/day	12,000 bbl/day
Spill Cause	Well blowout	Well blowout	Well blowout
Closest Land	50 NM	100 NM	On Land
Season	Fall (Sept. 27)	Fall (Nov. 8)	Summer
Spill Hazards	Fire & Explosion	Fire & Explosion	Fire & Explosion
Env. Conditions			
- Wind	SSE, 15 kts.	SE, 15-20 kts.	NE-SW, 0 - 20 kts.
- Sea State	Not specified	Not specified	0 - 2 ft.
- Current	NNW, 0.9 kts.	WNW, 0.9 kts.	0.15 kts.
- Visibility	Not specified	Not specified	Not Specified
- Precipitation	Not specified	Not specified	Not Specified
- Temperature	Not specified	Not specified	Not Specified
Spill Trajectory	NNW toward shore	WNW toward shore	E-NE at 0.6 kts.
Expected Oil Recovery	131,000 bbl/day Storage 17,922 bbl	43,000 bbl/day Storage 4169 bbl	121,000 bbl
In-Situ Burn			
- Feasible	Yes	Yes	Yes

- Currently Allowed	Yes	Yes	Yes
Sensitive Resources	Yes	Yes	Yes

4.0 Generic Scenario Development

Based on the information collected on past spills and scenarios taken from current contingency plans, it is possible to formulate a set of generic spill scenarios which can be used in developing conceptual systems for the two applications under consideration. These general scenarios provide the basic engineering parameters (primarily the spill rate) and operational requirements (primarily weather and sea conditions) for designing various devices, specifying support equipment, and formulating the general transport, deployment and operating procedures associated with each. No attempt is made to specify the various parameters that will dictate how useful the system will be in a specific situation which include source location (subsea or surface), gas/oil ratio, slick thickness, degree of emulsification and weathering, etc. The five generic scenarios are described as follows:

- Scenario I - Offshore Platform Spill in the Gulf of Mexico

Spill Volume: 100,000 bbl
Spill Rate: 10,000 bbl/day initial, decreasing to 1,000 bbl/day
Oil Type: Louisiana crude
Spill Duration: 30 days
Spill Location: Offshore from the Louisiana coast
Distance to Shore: 20 NM
Distance to Major Staging Area: 30 NM
Hazards: Toxic (hydrogen sulfide) and explosive gases near platform
Weather: Moderate, Temp 75°F, Winds 0-15 knots, Intermittent precipitation
Sea Conditions: Waves generally 1-3 feet, (up to 6 feet during storm), currents up to one knot
Response Methods: Mechanical recovery is possible but limited. Emulsification of oil occurs within 1-2 days of reaching the surface. Heavy oiling of coastal areas is anticipated. In-situ burning is approved.

- Scenario II - Offshore Platform in Cook Inlet

Spill Volume: 50,000 bbl
Spill Rate: 5000 bbl/day initial, decreasing to 1,000 bbl/day
Oil Type: Cook Inlet Crude
Spill Duration: 15 days
Spill Location: Inshore in Cook Inlet
Distance to Shore: 5 NM
Distance to Major Staging Area: 50 NM
Hazards: Hydrogen sulfide and explosive gases near platform
Weather: Moderate, Temp 30°F, Winds 0-20 knots, Intermittent precipitation
Sea Conditions: Waves 1 to 3 feet, up to 6 feet during storms, current up to 3 knots - tidal

Response Methods: Mechanical recovery is limited by current velocity in Cook Inlet and the presence of ice and debris. Because the spill site is removed from population centers, in-situ burning is approved.

- Scenario III - Onshore/Offshore Platform Spill, Prudhoe Bay

Spill Volume: 180,000 bbl
Spill Rate: 12,000 bbl/day initial
Oil Type: Prudhoe Bay Crude
Spill Duration: 15 days
Distance to Shore: 0 NM
Distance to Major Staging Area: 5 NM
Hazards: Toxic and explosive gases near platform, broken and solid ice most of the year
Weather: Potentially Severe, Temp -30°F to +50°F, Winds 0-25 knots, snow
Sea Conditions: Waves up to 2 feet during open water, current up to 0.5 knots
Response Methods: Mechanical recovery is effective in open water conditions, but not in heavy ice concentrations. Oil reaches and is transported along shoreline, requiring shoreline cleanup and countermeasures. In heavier concentrations of solid and broken ice, the ice itself serves as a containment mechanism. In-situ burning is considered an option by the On-Scene Coordinator.

- Scenario IV - Shallow-Water Spills for Marshes, Mud Flats, Lagoons, and Tidal Creeks

Location: Remote - equipment must be transported by light vehicles and spill cleanup personnel
Oil Type: Light crude or fuel oil that remains burnable for several days
Environment: Highly sensitive area, non-intrusive cleanup techniques required
Nearest Logistics Staging Area: 20 NM
Water Depth: 1-3 feet
Current: 1-2 knots tidal
Response Methods: Intrusive mechanical recovery is precluded by the sensitivity of the area. However, free oil is flushed out of marsh into shallow, open areas by tidal action and cold water flushing. Because of the remoteness of the area, and lack of viable cleanup methods, in-situ burning is approved.

- Scenario V - Shallow-Water Spills in Rivers and Along Shorelines

Location: Remote - equipment must be transported by light vehicles and spill cleanup personnel
Oil Type: Light crude or fuel oil that remains burnable for several days
Environment: Sensitive area, non-intrusive cleanup techniques preferred
Nearest Logistics Staging Area: 20 NM
Water Depth: 1-3 feet
Current: 1-2 knots tidal

Response Methods: Oil is transported along shoreline and can be concentrated using shore as a barrier in shallow-water areas where the current is moderate. Mechanical recovery is difficult because of the remoteness of the site and the resulting difficulty in staging mechanical recovery equipment and removing collected oil. Because of this, and lack of other viable cleanup methods, in-situ burning is approved.

5.0 Development of Conceptual Systems for Oil Burning

The next step in determining the feasibility of alternative approaches for burning oil in offshore, continuous-source spills of long duration and shallow-water situations is to develop a series of conceptual system designs, including the burning devices and supporting equipment, the transportation and deployment schemes, and the operating procedures for implementation on- scene. The concepts proposed center on two fundamental approaches. For the long-term, continuous source offshore spill, the approach is to provide a simple, durable combustion vessel which can collect and concentrate the oil, withstand the heat of combustion for long periods of time, and be seaworthy enough to remain on-scene even if oil combustion must be temporarily suspended by severe weather. For the shallow-water application, the basic approach is to develop a containment mechanism that is modular and lightweight so that it can be easily transported and deployed in remote locations, is durable enough to survive prolonged burning, and can be used in a manner that capitalizes on existing current flow (rather than being towed by attending vessels). The conceptual designs consider simplicity and durability as highly desirable attributes and focus on the creative use and extrapolation of existing equipment and techniques.

5.1 Assessment of Relevant Technologies

In expanding upon these two approaches to conceptual systems that could be used in these two applications, it is important to consider the various oil spill technology development efforts that have been undertaken to date, as various devices and techniques developed for in-situ burning in general may be applicable to the systems envisioned. A brief synopsis of various relevant technology efforts is provided below. A more in-depth review of selected technology development efforts is provided in Appendix A. An excellent overview of in-situ burning technology development efforts is provided by Buist *et al*. (1994a).

Fire-Resistant Containment Booms

In developing alternative concepts and devices for in-situ burning of oil, it is important to keep in mind the nature, advantages and disadvantages of the technology that forms the standard approach to in-situ burning. This technology is the fire-resistant/fire-proof oil spill containment boom. The term “fire-resistant” is generally employed in describing these devices as they will generally suffer some deterioration when exposed to flame for longer perods of time. These booms have been under development since the late 1970s and have subsequently been manufactured, marketed, and tested under full-scale conditions at sea. Such a boom (manufactured by 3M Corporation) was used during the EXXON VALDEZ spill.

Fire-resistant containment booms fall into two general designs. The most common are those constructed of fire-resistant fabric which are similar in design and appearance to regular oil spill containment booms, but are covered with a fabric that is designed to remain intact when exposed to heat and flame. There are currently several such booms listed in the World Catalog of Oil Spill Cleanup Products (Schulze,1997). A more complete description of this technology is provided by Buist et. al. (1994a). These booms represent a proven technology available at a moderate cost. They can be easily transported by air or ground, and can be deployed with a reasonable amount of effort. *Their major unresolved limitation is the tendency to deteriorate and eventually fail when exposed to fire for longer periods (6-10 hours) while under the mechanical stress caused by waves and current*.

The second type of fire-resistant boom is constructed of stainless-steel which is far more durable when exposed to heat and flame. Stainless-steel booms have been under development since the late 1970s. Dome Petroleum Ltd. constructed and tested a full-scale prototype both at the OHMSETT facility (burn tests) and at sea (seekeeping tests without oil). These tests clearly showed the ability of the stainless steel design to withstand high temperatures for extended periods of time, contain oil in sea states of at least 2-3 and currents of 0.4 m/s (~ 0.75 knots); and survive, without damage, for long periods at sea (Buist *et al*., 1983). *The drawbacks for these booms are their size and weight (which complicates transport, deployment and retrieval); and their relatively high cost*.

Although several versions of this device have been produced and commercially marketed over the years (Buist *et al*., 1994a), the only design currently listed in the World Catalog of Oil Spill Cleanup Products is the Spill-Tain Boom (Schulze, 1997). More recently, Environment Canada and MMS have commissioned a research and development effort by S.L. Ross, Ltd to refine the original Dome Petroleum design to make it easier to handle and less costly. The strategy for employing such a boom would be to use it at the apex of the towed fire-resistant boom configuration where temperatures and heat flux are most intense. The remainder of the boom configuration would be standard fire-resistant boom such that the stainless steel portion is referred to as the “pocket boom”. *If successful, the “pocket boom” configuration will provide another alternative for handling longer-term burn operations, including those resulting from blowouts*.

Another approach to extending the life of the fire-resistant boom is to develop a water-cooled version where oil is continuously pumped through the boom to prevent heat damage. A prototype is being developed and tested by Spiltec Inc., and if successful, should allow continuous burning in a single boom for one to several days (Personal communication with A. A. Allen, April, 1998). The pumps to supply the cooling water are located on the tow vessel. *The water-cooled boom would also provide a viable approach for dealing with offshore, continuous source spills assuming that current and wave conditions allow for oil containment in the boom*.

Shoreside Oil and Oiled Debris Incinerators

A number of designs for shore-based oil and oiled debris incinerators have been developed, implemented and tested. These include a rotary kiln incinerator developed by Trecan, Ltd. and tested by Environment Canada (Meikle and Ewing, 1980), a prototype pit incinerator also developed by Trecan (Meikle and Ewing, 1980), and an air curtain incinerator (Kruk, 1983). All of these incinerators consist of an enclosed combustion chamber (circular for the rotary kiln incinerator, rectangular for the pit incinerator and air curtain incinerator). Air is supplied to the combustion chamber by blowers which stimulate circulation thereby enhancing combustion efficiency and reducing visible emissions (smoke). The primary use of the three incinerators is disposing of oil contaminated sediment, oiled debris, and oiled sorbent material. The air curtain incinerator was tested with pure oil demonstrating a system capacity of 685 bbl/day (in a 10 ft. long x 10 ft. wide x 14 ft. high chamber with airflow at 7,000 cu. ft./min.). *These development efforts demonstrated that burning efficiency can be enhanced and emissions controlled using a simple combustion chamber and supplying forced air to both meet the stoichiometric air requirements for oil combustion, and promote the efficient distribution of air throughout the burn area thereby enhancing the combustion process.*

Oil Burners/Flaring Devices

A number of oil burners/flaring devices have been developed and tested for disposing of oil from exploration and production activities and oil recovered during spill cleanup. These devices mix oil and air together in a fluid stream and then ignite it as it is injected into the atmosphere. Systems sometimes use the injection of lighter products to enhance burning (e.g. diesel oil), and use water or steam to suppress emissions and prevent back radiation to the equipment and personnel. Several devices were developed in the 1980s with the intended use being the on-site disposal of oil collected using mechanical recovery equipment. On-site disposal was required by the remoteness of anticipated spill sites (e.g., Canadian Arctic and Alaska) and the difficulty in transporting recovered oil to a suitable reclamation or disposal facility. These devices included two versions of a rotary cup burner (Buist and Vanderkooy, 1982; Buist, 1989). These systems used centrifugal force to atomize oil and burn it with airflow enhancement provided by blowers. The devices were able to burn oil and oil/water emulsions (with 60-80% water) with little or no visible smoke. Capacities of 500 barrels per day (BPD) were achieved in tests of the final prototype.

Another somewhat more complex design developed by the U.S. Coast Guard (USCG) consisted of a series of twelve burner nozzle assemblies mounted on an 80-foot boom in a fan-shaped pattern (Beach and Lewis, 1983). Each burner nozzle assembly consisted of an oil nozzle, an air nozzle and a liquid propane igniter. Water spray was used to suppress smoke and thermal radiation. Required support machinery included an oil pump, a water pump, and three air-compressors all of which were diesel driven. The device could process emulsions of up to 30% water, with oil processing capacities of up to 5,100 BPD.

More recently, Expro Ltd. in the UK has developed a single flaring burner head capable of handling 5,000 BPD. Compressed air and oil are mixed in the burner head and ignited. Supporting machinery again includes an oil pump, water pump, and three compressors (two in use and one as backup). Emulsions of up to 60% water can be burned with no visible emissions. With a three-burner head configuration, processing capacities of up to 15,000 BPD can be achieved.

Modern flaring burners thus supply a viable means of burning oil at rates that exceed the maximum oil discharge rates specified in the design scenarios (5,000 and 10,000 BPD). The challenge in utilizing this technology is providing a continuous supply of oil to the device and providing a platform and logistics to support the ancillary machinery required by the system.

Marine Vessel Oil Spill Incinerators

The concept of using a floating incinerator to burn oil spills at sea has been proposed and investigated in a number of studies. These are summarized in Appendix A and described in some detail by Buist *et al*. (1994a). Two conceptual designs were proposed by Pittsburgh Corning in the early 1970s for floating combustion chambers into which oil is injected after being removed from the water by mechanical recovery. The combustion chamber allows concentration of the oil and airflow enhancement and prevents heat loss to the ocean resulting in a more efficient burn. One concept included the injection of glass beads to enhance burning. Patents were obtained for these two devices but prototype development was not pursued. Another device, known as the Elijah Burner was investigated by British Petroleum, resulting in a small, proof-of-concept prototype capable of burning 40 liters/hr (6 BPD). Further development was not pursued.

In addition to incinerators for burning oil collected from the surface, conceptual designs for incinerators to burn oil from pipeline leaks and blowouts were also investigated. The pipeline leak burning device consisted of a burner head and heat dissipating screen that could be positioned at the surface over the subsea leak. This concept was also patented but never taken beyond the design stage. Dome Petroleum designed a similar device which could be positioned over a subsea blowout to collect oil at the wellhead and burn it at the surface in a controlled manner (Buist and Potter, 1982). Preliminary design work and scale-model tests were conducted, but a full-scale prototype was never constructed.

Attempts have been made to develop enhanced efficiency burning devices using acoustic energy, air jets, and enhanced air circulation techniques (Buist *et al*., 1994a). In the early 1980s, Koblanski (1983) experimented with the use of acoustic energy to atomize oil at the oil/water interface to improve efficiencies and suppress emissions. A similar technique used pneumatic nozzles to entrain and atomize oil at the oil/water interface. Both concepts were implemented in small working prototypes which demonstrated that enhanced oil combustion could be achieved. The primary problem with both devices is their inherent complexity, the logistics of supplying acoustic energy (via transducers) and compressed air at sea, and the limited oil burning capacity. Although both systems have been refined and commercialized, neither is currently used in spill response.

Following the EXXON VALDEZ spill, a research effort was undertaken by researchers at the University of Arizona to develop an enhanced incineration scheme that utilizes air circulation vanes to induce a circular combustion pattern (known as a “fire whirl”) to increase burn efficiency and suppress smoke (Franken *et al.*, 1992). Tests of the passive air vane circulation scheme demonstrated increased burn efficiencies and up to 50% smoke reduction. Modifying the vane shape and placement pattern did not alter the result. In general, the researchers concluded that the use of passive air flow enhancement using vanes was not going to be practical in larger-scale burning applications. Follow-on tests of circulation enhancement using vanes by Alaska Clean Seas (1991) and Marine Spill Response Corporation (Nordvik *et al.*, 1995) showed no appreciable increase in efficiency using vanes for air flow enhancement.

Further tests in the University of Arizona study showed that injection of air in combination with the enhanced natural circulation could further boost burn efficiencies. A prototype incineration chamber/stack device (1.8 m in diameter by 9.8 m high) was constructed and tested, demonstrating an average burn rate of 860 BPD, and a peak burn rate of 2,540 BPD. *Based on this prototype design, it was postulated that a larger seagoing version of the combustion chamber could achieve a peak burn rate of approximately 4000 BPD, and would be mounted on a standard vessel hull form.* The projected cost of such a device (based on a per pound estimate derived from barge construction data of $3.00 per lb. of displacement) was $120,000 each (assuming production of 100 units).

This fundamental incinerator design has been incorporated into the design of an arctic incinerator barge in a study sponsored by Shell Western E&P in Alaska (Glosten *et al.*, 1991). The barge itself is 144 feet long, 60 feet wide, and has a draft of 11 feet. The displacement of the barge is 890 long tons. *The barge envisioned has a skimming capability for collecting oil at one end and transporting the oil into the circular burn chamber (11 m diameter by 10.3 m high) based on the U. of Arizona design, providing a burn capacity of 2100 BPD based on an 11 meter (36-foot) diameter burn area.* The barge has a grate and rotating disk assembly that allows it to operate in light broken ice. Onboard machinery and support systems include air supply blowers; pumps for moving oil and water into the barge; ballasting and cooling water circulation; a helitorch-like ignition system, an AFFF extinquishing system; and generators. The barge would cost approximately $4.15 M to construct.

Efforts to develop marine oil incinerators have not yet produced a viable prototype but show promise as the burn rates are approaching the release rates that might be encountered in an actual major offshore spill. The University of Arizona concept, because of its simplicity and relative efficiency, may be a viable option in an application similar to the Shell Western E&B incinerator barge. Incineration using such devices offers the advantage of controlled combustion with enhanced efficiency and smoke suppression. Additives such as burning promoters, emulsion breakers, and smoke suppressors (e.g., ferrocene) could also be injected *as the incinerator platform can accommodate additive injection systems. The primary drawback of such a device is its relative cost as compared to fire-resistant booms.*

Alternative Oil Collection and Concentration Schemes

Several alternative methods, other than the use of standard fire-resistant boom, have been proposed for containing oil during burning. These include the use of natural containment (e.g., using logs, floating ice, snow and the shoreline itself) to concentrate oil, as well as more complex systems such as bubbler curtains and water jets. These alternatives may be particularly useful in shallow water and in marsh areas when wind and currents are light to moderate.

Logs have been used on at least two spills where burning was conducted (Mackenzie River pipeline spill, 1958, and Rivers Inlet B.C. spill, 1990). Several oil spills which have occurred where ice confined the oil and permitted burning immediately, or as the ice melted (e.g., Tralhavet Bay, Sweden, in 1970; Vessel IMPERIAL ST. CLAIR on Lake Huron in 1976; Barge BOUCHARD #65 on Buzzards Bay, Mass., in 1977, and the Vessel EDGAR JOURDAIN in NWT in 1980) as reported by Buist *et al.* (1994a). *Incidents such as these demonstrate that simple, readily available materials can often be used to assist in-situ burning operations.*

More sophisticated, technology-oriented methods have also been investigated. Several investigators have proposed the use of submerged, perforated air pipes or hoses to contain burning oil using an air or water generated current barrier. Problems inherent in this approach are the machinery requirements for providing high flow rates of compressed air, correctly ballasting and maintaining the hose at an even depth in offshore waves and currents, and the low failure velocity of the air bubble barriers (as low as 0.2 m/s or 0.4 knots). Williams and Cooke (1985) found that using porous canvas hose with a blower provided effective containment without the need for a compressor for water depths of one meter or less, with little or no wind and current. The second and third constraints are not limiting in shallow, flat-bottom areas such as mud flats, marshes and tidal creeks. *Thus the air bubbler system may be a countermeasure of opportunity in situations involving shallow water and low current flow (perhaps up to 0.5 knots). Further testing in waves and current will be needed to confirm this.*

Water-jet barriers have also been considered as a containment mechanism for burning oil (Purves, 1978; Comfort *et al.*, 1979; Comfort and Punt, 1989). However, tests have shown that containing oil in less than quiescent conditions requires high pressure spray which can reduce the efficiency of the burn. In addition to requiring machinery (water pumps), there must be some means of supporting the spray nozzles and aiming them in the proper direction. This makes deployment and operation a logistical challenge, even in shallow-water applications. *Accordingly, water spray systems are not generally viable in this application.*

Oil Burning Additives for Enhanced Burn Efficiency and Emissions Control

A number of additives have been developed to promote burn efficiency and control emissions (primarily visible emissions) during oil burning operations. Burn promoters generally serve as insulators and wicking agents in enhancing oil burning. They include powder products (e.g., Cab-OSil, Aerosil, and Tullonox), fiber and granular substances (e.g., Fibreperl, Ekoperl, Wonderperl, Vermiculite and Peat Moss), and cellular glass beads (commercially marketed as Seabeads). Each substance is spread throughout the oil slick at the oil/water interface, and each has been shown to enhance burning to some extent. Emulsion breakers can also be used to promote combustion by reducing the water content of the oil (to less than 60% water) to allow for ignition and enhanced burning. Emulsion breakers can be added at the same time as other additives using the same distribution system. The primary difficulty in using such substances for in-situ burning is the high dosage rate and the complicated logistics in distributing the additive over a wide area of the spill.

A number of organometallic compounds have been investigated as smoke-suppression agents. The most successful of these has been ferrocene which as a crystalline solid is insoluble in water, slightly soluble in oil and non-toxic. Tests of ferrocene applied to oil as a smoke suppressant have shown that a 90-95% reduction in soot is possible with addition of as little as 2% of the ferrocene compound by weight (Mitchell, 1990; Mitchell and Janssen, 1991). Moir *et al*. (1993) have reported that the latest ferrocene hybrid, RMS 9757, reduces soot up to 70%, with addition of 0.5% of the additive by weight. Although the dosage rates for ferrocene are reasonable, application in open burning at sea is still limited by the logistics of transporting large quantities of the additive to the spill site and distributing it evenly over the slick. In addition, the ferocene must be mixed in another compound so that it does not sink. Another limiting factor for ferrocene is its cost (approximately $400/lb. for the pure substance).

Another straightforward burn enhancing, smoke-suppressing additive investigated recently is compressed air. Tests conducted by Marine Spill Response Corporation (Nordvik *et al*., 1995) looked at the effect of compressed air supplied from both surface jets and a submerged bubbler system on the burning of oil in a contained area. The air jets above the surface clearly reduced the amount of smoke (based on qualitative observations) but were sensitive to the ambient wind. The bubbler system appeared to be somewhat less effective in reducing smoke but was not impacted by the wind. Although neither of these burn enhancing techniques is applicable for in-situ burning within a fire-resistant boom at sea, they may be effective in enhancing burning in an enclosed area such as in a floating incineration vessel.

With respect to the alternative applications envisioned, the application of emulsion breakers and smoke suppressants may prove viable and beneficial. The effectiveness of both of these additives has been verified, and the logistics of transporting and distributing them is simplified by having the oil burned in a smaller area, with ample space for distribution systems (e.g., on the deck of the oil burning barge or on the shore). In addition, the enclosed area and staging platform provided by the floating oil burning vessel may allow for the use of blowers to supply forced air as a burn enhancing additive, as proposed for the arctic incinerator barge concept *investigated by Shell Western E&P (Glosten et al., 1991)*

Ignition Techniques and Devices

A number of compounds, devices and systems have been investigated and tested for igniting oil slicks at sea (Buist *et al.*, 1994a). Compounds investigated include sodium and gasoline, hypergols, solid fuels (e.g., gelled kerosene), solid propellants (rocket fuels), sodium and gasoline, and proprietary chemical mixtures such as Westcom 2000. All of these compounds are effective in igniting oil, the major constraint for their use being the difficulty in keeping them at the oil/water interface, and in some cases, the need for a secondary igniter. These compounds are also inherently highly flammable and/or explosive requiring extreme caution in handling, transport and storage.

Various hand-deployed devices have been used for oil slick ignition, including incendiary devices such as marker flares and thermite grenades, as well as devices specifically designed for igniting oil slicks (e.g., the Canadian EPS or “Pyroid” igniter, and the Dome Petroleum/Energetex igniter). These devices are constructed to float at the oil/water interface and are safe for transport and storage aboard aircraft and vessels, being armed only at the moment of deployment. They need only be stored in a spark free, dry area, away from heat sources and other flammable material. Both igniters were commercially produced, but are not longer readily available for immediate procurement and use. A more recently developed hand-held igniter developed by Spiltec, Inc. consists of a nalgene bottle filled with gelled gasoline, and a distress flare, mounted in a styrofoam float. Such a device has been successfully tested (Guenette and Thornborough, 1997) and can be easily constructed on-scene.

The current system of choice for igniting oil during in-situ burning operations, particularly for large spills where several fire-resistant booms are deployed, is the Helitorch system, commonly used for setting backfires in controlling forest fires. It is a completely self-contained system consisting of a fuel barrel (filled with gelled gasoline or a gasoline and diesel mix), and a pump and motor assembly mounted on a support frame. The gelled fuel mixture is ignited by an electric filament and propane jet ignition system. The burning fuel is delivered in a highly viscous stream that breaks into burning globules before hitting the surface. The system, which is slung from a helicopter (hence the name Helitorch) during operation, is flown at a speed of 40 to 50 km/hr, at an altitude of 8 to 23 meters. This provides for an even distribution of the burning fuel over a wide area. Recent tests during an in-situ burn demonstration in the United Kingdom have confirmed the utility of the Helitorch for igniting oil during in-situ burning operations (Guenette and Thornborough, 1997). These tests also demonstrated the feasibility of incorporating an emulsion breaker into the napalm mixture to allow ignition of emulsified oils.

Of the systems described above, the Helitorch concept is most relevant to the marine incinerator concept as it allows for ongoing ignition as required. The other compounds and devices are tailored for a one-time ignition and burn such as with the fire-resistant boom or a large pool of oil on the shoreline. For ignition of spills contained in shallow water, simple *floating igniters that can be allowed to drift into the oil (e.g., a plastic bag with gelled fuel, or kerosene/diesel soaked piece of sorbent, or the Spilltec igniter) will probably be sufficient.*

Lightweight, Modular Spill Response Equipment

A primary desirable attribute for any oil spill response device system is ease of transport and deployment, particularly in remote locations where spills often occur. To this end, oil spill equipment and system developers have designed systems to be modular (transportable in sections) and lightweight. Many of the systems currently available can be broken down and transported by truck, and often by aircraft (a requirement for most Coast Guard Strike Team systems is that they be C-130 transportable). The use of modern, high strength materials and fabrication techniques has led to further advances in this area, such as the development of collapsible oil storage barges and oil storage bladders (e.g., the Lancer Barge and Pollutank). *It is likely that the smaller devices proposed for the alternative applications of in-situ burning can incorporate this modular approach to achieve some measure of transportability.*

5.2 Review of the In-Situ Burning Process

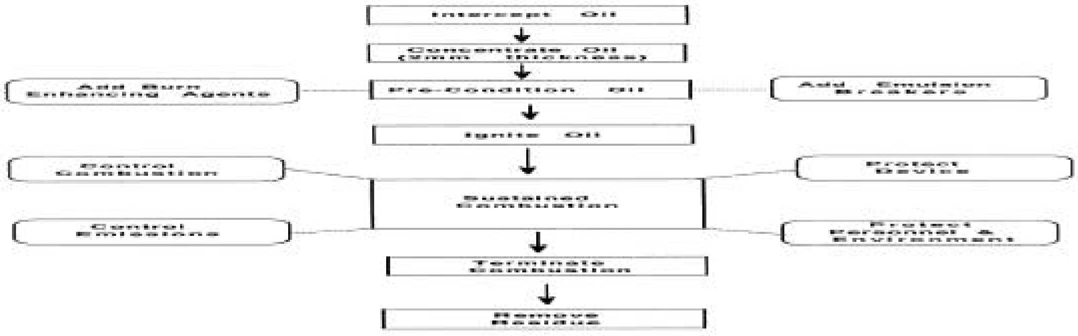
Regardless of the approach and technology utilized in the burning of spilled oil, a number of steps must be followed and several issues addressed to ensure that the operation is both successful and safe. This applies to the use of any burning device whether it be a fire-resistant boom or oil burning vessel. A schematic of the overall process is provided in Figure 5-1.

The first step in the process is to locate, intercept and concentrate the oil to a thickness that will support in-situ burning (generally 2 mm or more). This involves towing the device through the oil (such as in using a fire-resistant boom for an offshore, open water spill), or positioning the oil in a current to intercept the oil (such as in a river or tidal estuary). The amount of boom deployed and swath width required depend on the thickness of the oil encountered. The ideal tow speed (or relative current velocity) when using fire-resistant boom is 0.75 knots or less. The volume of oil per unit time reaching the apex of the boom or combustion device will be equal to the tow speed (or relative current speed) X the swath width X the oil thickness.

Once concentrated, the oil can be pre-conditioned with various additives, to break emulsions for enhancing burnability, or to suppress visible emissions (smoke). This can be best accomplished where oil is concentrated on the shore, in ice or in a combustion device, and for smaller spill volumes. It becomes impractical for larger spills contained in booms due to the difficulty in transporting and distributing large amounts of additives.

After the oil is concentrated, the next step is to ignite the oil in such a manner that the combustion process is self-sustaining. Assuming that wind and sea conditions are moderate, this can be accomplished with a hand-held device or a more sophisticated ignition system such as the Heli-torch. For larger spills requiring continuous burning over longer periods of time, a device capable of re-igniting the oil on demand (e.g., the Helitorch) will probably be required.

Once the oil has been ignited, the goal is to maintain steady combustion at as high a burn rate as possible, while protecting the equipment, spill response personnel, and the environment from undue harm. Protecting equipment will require the use of insulation and or a cooling scheme and possibly controlling the intensity of the burn. Heavily damaged equipment will have to be replaced as required. For the most part, protecting personnel requires keeping them far enough from the burn so that flame radiation hazard and toxic emissions are not an issue (that is, no protective equipment is required). Protecting the environment involves making sure that heat and emissions do not unduly impact human populations and marine resources. This is generally



accomplished by only conducting in-situ burning three or more miles offshore, or in isolated nearshore areas. However, in some instances the active control of emissions is desirable. After the combustion process is complete, burn residue should be recovered if at all possible.

The final consideration is the ability to terminate the burn in an emergency such as caused by severe weather, damage to equipment, marine birds and mammals being sighted in the area of the burn, or by wind shifts which will carry emissions toward populated areas.

5.3 Alternative Conceptual Designs Proposed

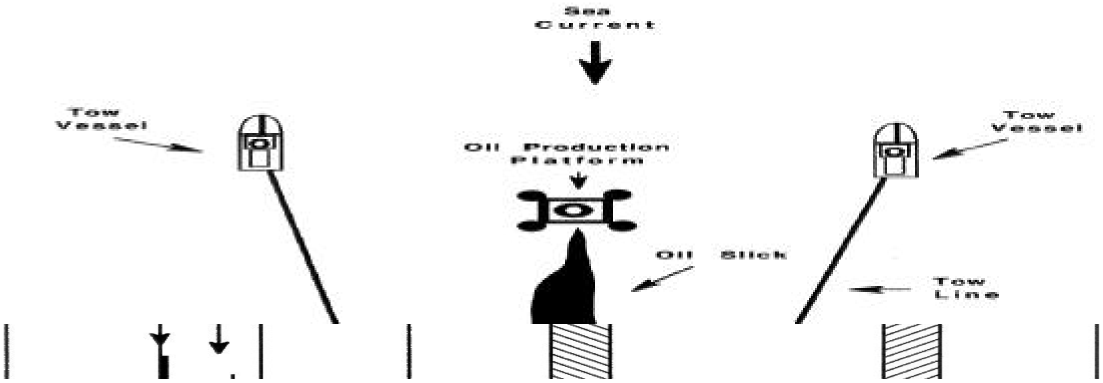
Based on the nature of the design scenarios outlined in Section 4.0, and the various technology development efforts to date, several conceptual designs can be proposed to implement and enhance the process depicted in Figure 5-1 for continuous, offshore burning operations, and spills in shallow water. Concepts I through III below address the continuous, offshore spill, while concepts IV and V address shallow water spills in rivers and coastal areas.

Concept I - Simple Oil Burning Barge

Concept I is a simple incineration barge that is fabricated using a standard barge hull-form. The center decking and bulkheads in the center tanks are removed to create a burn area in the interior. Wing tanks are kept in place to provide flotation. An opening is cut into the bow to allow for the entry of oil, and a skimming device (specifically a simple weir and/or submersion plane skimming device that relies on the relative motion of the device through the water to skim the oil from the surface) is used to concentrate the oil. Water exits the barge through ports in the bottom and/or stern. If necessary pumps can be installed at the outlet ports to enhance flow through the device. The barge is strengthened and insulated to withstand heat generated during combustion. The barge is used in conjunction with conventional boom and fire-resistant boom to capture and concentrate the oil, or could be used as an on-site incinerator for oil collected using conventional mechanical recovery techniques. The device is depicted in Figure 5-2. The deployment scheme for the device (as well as those described in Concepts II and III) is shown in Figure 5-3.

Design and operating considerations to be investigated include:

- Optimum size for burn capacity and ease of deployment
- Whether to construct the device or modify an existing barge (subject to hull availability)
- Insulation requirements and/or cooling mechanisms for the hull during burning
- Incorporation of skimming and oil separation techniques to improve efficiency (simple weir or inclined plane skimmer)
- Requirement for pumps to facilitate oil and water flow into the barge
- Handling broken ice and debris
- Ignition mechanisms and burn extinguishing measures



Concept II - Modified Oil Burning Barge

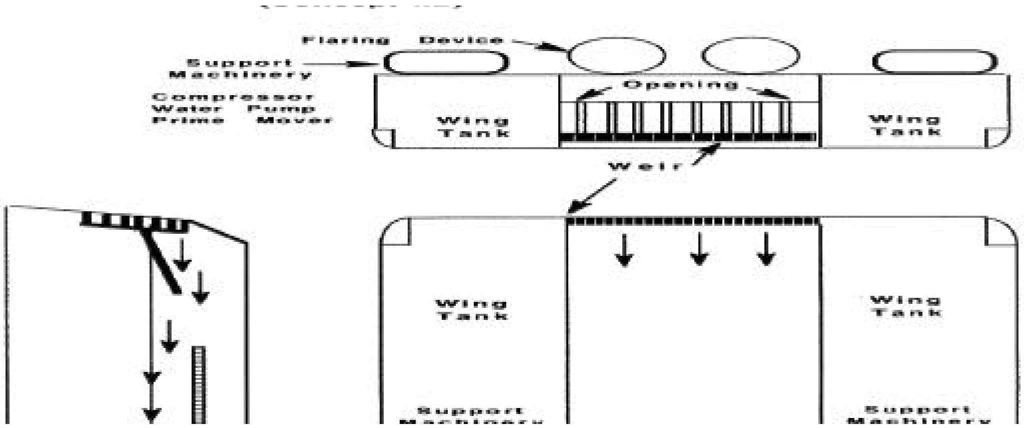
This device is a modified version of the simple barge described above equipped with combustion enhancement devices to promote burn efficiency and reduce air emissions. It is particularly useful in coastal areas where air quality considerations would preclude conventional in-situ burning techniques. Two possible design options will be considered. The first is to incorporate airflow enhancement measures (e.g., passive air scoops or active blowers) into the combustion chamber as shown in Figure 5-4 (Concept IIA). The second measure is to install an oil flaring device onboard the barge such that oil is pumped from a central collection area and concentration device within the barge hull (such as an internal weir skimming device), to the flaring device mounted on deck, and burned in a controlled manner (Concept IIB). This device is depicted in Figure 5-5.

Design and operating considerations to be investigated (in addition to those investigated for Concept I) include:

- The feasibility of optimizing airflow to enhance burn efficiency (passive airflow enhancement vs. blowers) in Concept I.
- The availability of flaring devices to implement Concept II
- Accommodating the necessary ancillary systems to support a flaring device.
- Incorporation of combustion enhancement measures and additives (e.g., wicking agents, emulsion breakers)
- Incorporation of other emissions control measures (e.g., air injection at oil/water interface, water spray at exhaust port, ferrocene distribution system)

Concept III - Collapsible, Easily Transportable Oil Burning Barge

This concept is similar to the barge concepts described above (Concepts I and IIA) but is designed to be transportable in sections, with inflatable or solid flotation chambers. The basic hull form is depicted in Figure 5-6. Inflatable hull technology similar to that employed in fabricating the currently available inflatable oil storage containers should be considered. The barge-like device is fortified with insulation and/or cooling mechanisms to allow it to withstand prolonged exposure to the heat generated from the burning oil. A skimming device (specifically a simple weir and/or submersion plane skimming device that relies on the relative motion of the device through the water to skim the oil from the surface) is used to concentrate the oil. It can be used in conjunction with conventional and fire-resistant boom to capture and burn oil or used as an on-scene incinerator for oil collected using conventional techniques. It can be configured as a shallow-draft device for use in shallow water. Depending on size and weight limitations, emissions control measures may be considered; however, onboard machinery should be kept to a minimum to preserve simplicity, reliability and transportability.



Design and operating considerations to be investigated include:

- Optimum size for burn capacity and ease of transport/deployment
- Feasibility of using an inflatable or modular solid hull
- Insulation and/or cooling schemes (e.g., ceramic coatings, ceramic insulation, water cooling)
- Adaptation of an existing skimmer design for oil collection/concentration (weir or submersion plane design)
- Smoke-suppression systems (e.g., passive airflow enhancement, simple ferrocene distribution system)
- Ignition systems and extinguishing measures

<u>Concept IV - Air or Water Bubbler System for Shallow Water</u>

This concept has been investigated in the past as a basic oil containment measure and as a means of concentrating oil for in-situ burning. The envisioned system consists of a water or air delivery device (water pump or air compressor/blower) and lengths of porous or perforated hose that rest on the bottom of a flooded area as shown in Figure 5-7. The concept is attractive for remote, shallow-water coastal applications as the system (pumps and hoses) can be easily transported to a remote site. The shallowness of the water (less than 1 meter) enhances the effectiveness of the air or water barrier. Oil would be captured as it is advected by tidal currents or outflow from creeks and inlets, or possibly as it is flushed out of marshes, mangroves or mudflats using water deluge techniques. Although this approach may not have widespread application, it may prove very efficient and logistically viable in certain scenarios.

Design and operating considerations to be investigated include:

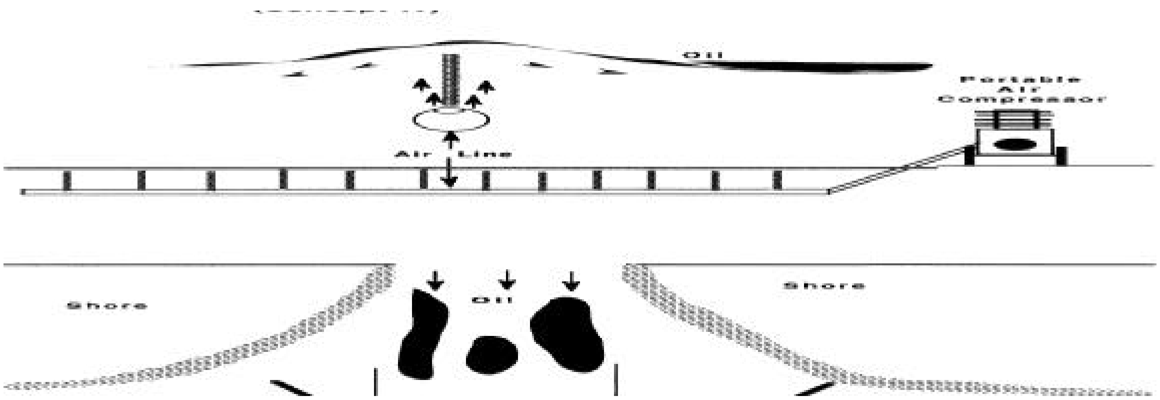
- Overall effectiveness of containment - maximum current velocity that can be accommodated
- Compressor or pump capacity, size and weight

- Hose deployment and anchoring techniques
- System configuration for ease of transport and deployment

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

This approach 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. The basic design and deployment scheme are depicted in Figure 5-8. A variation of this type of barrier is currently used to provide temporary containment around oil storage tanks on land. 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.
Design and operating considerations to be investigated include:

- Materials and fabrication scheme
- Connectors and anchoring
- Deployment strategies


Oil
Portable
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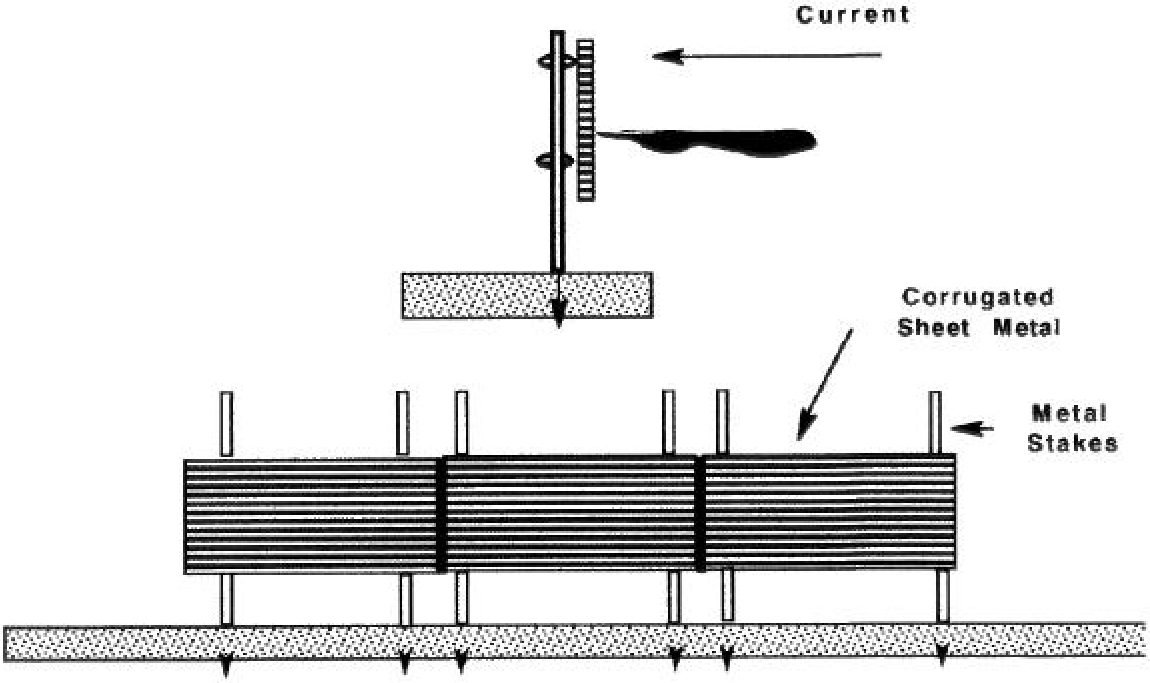
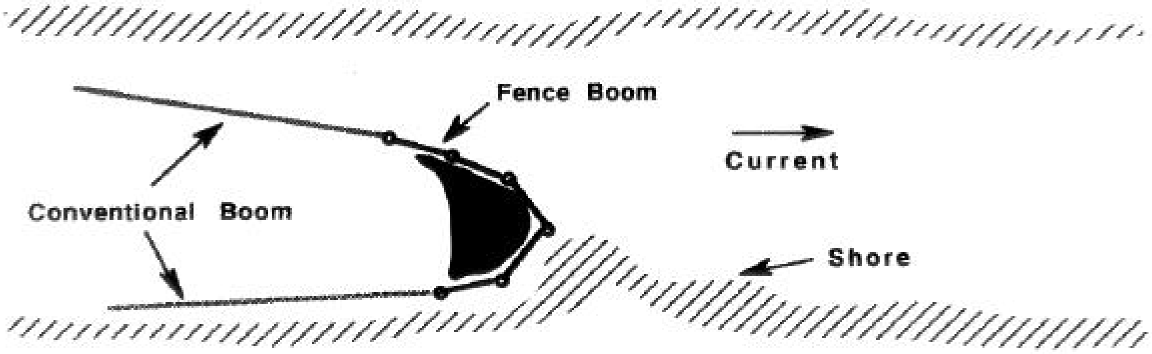




No numbering

6.0 Evaluation of Engineering Design Considerations

After describing the several conceptual systems in Section 5.0, the next step in determining overall feasibility is to address the various engineering design considerations associated with each. These considerations include:

- Overall size and configuration of each device/system (dimensions, weight, components)
- Oil processing capability which is determined by both the oil recovery rate and the burn rate
- Hydrodynamic stability for Concepts I-III (derived from model calculations)
- Seakeeping ability for Concepts I-III, and utility and durability in waves and currents for Concepts IV and V
- Choice of materials for fire resistance
- Insulation and cooling mechanisms to protect the device
- Mechanisms for igniting the oil (including provisions for re-ignition)
- Fire suppression and extinguishment (for both normal operations and emergencies)
- Oil residue capture and removal after burning
- Time and cost to construct the device
- Inspection and certification requirements

The analysis of engineering design considerations is summarized in the following Summary Evaluation Matrices (6.1 through 6.12). The unabridged analysis (including calculations and discussions) is contained in Appendix B.

The overall feasibility of having each concept meet the various engineering design requirements and criteria under each topic is expressed using a qualitative feasibility rating. The qualitative rating scheme is as follows:

V.F.	Very Feasible (engineering criteria can clearly be met; constraints can be overcome)
F	Feasible (engineering criteria can probably be met; some constraints will require significant effort but can be overcome)
N.F.	Not Feasible (engineering requirements will be difficult to meet; many intractable)
N/A	Topic is not applicable to this concept

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN

Topic	Concept I	Concept II	Concept III	Concept IV	Concept V
6.1 Overall Size/Configuration	V.F.	V.F.	V.F.	V.F.	V.F.

Concepts I & II - Initial strategy for Concepts I and II is to use existing barge hull. The overall size and configuration of the barges which are primarily determined by the need to create a burn area (“burn pool”) large enough to process roughly 5000-10,000 barrels per day (BPD) of oil. Investigations show that the standard 2,713 gross ton barge (25 ft. x 76 ft. x 17 ft. draft) provides a suitable hull form with center tank that can be opened up for burning. In addition to the simple burning barge concept proposed in Concept I, integrating an enhanced airflow system into the design (Concept IIA), and adding a flaring device which would be mounted on deck (Concept IIB) are viable options. The enhanced airflow system can consist of simple air scoops or involve aerators and stack configurations which induce circular airflow (as proposed by Franken *et al.*, 1992). Modern oil flaring technology is providing burn rates on the order of 5,000-10,000 bbl/day.

Concept III - The device envisioned consists of a modular, easily-transportable hull form that collects and burns the oil in a single operation. A hull form was identified which closely matches the general size and shape of the device, that is, the HIB Skimmer currently available from Hyde Products, Inc. The HIB skimmer is a versatile, high speed (up to five knots and above) oil concentrating device. The device employs an enhanced submersion plane technology which uses the relative motion of the fluid and the device (either towed or held stationary in a current) to force the oil/water mixture down the bow and into the separation tank. Baffled decks in the tank (or in this case the burn area) slow the movement of the mixture, allowing the oil to form a thick layer on the surface while the water exits through vents in the bottom of the device. Implementing Concept III would require scaling up the design to provide a burn area of sufficient size, choosing materials and/or insulating the device to withstand the heat from the fire, and ideally incorporating a modular design scheme to allow transport in sections and assembly on scene. Two units were conceptually developed by the designers Webster Barnes, Inc., - a 180-foot LOA unit, which has the full required burn area; and a 100-foot LOA unit. It appears that a somewhat smaller (75-100 foot), modular version of the device could be fabricated in sections for ease of transport.

Concept IV - This system includes up to 500 feet of porous hose weighted by galvanized chain. Hose should be provided in short sections (20-25 feet) for ease of deployment/retrieval. Because of the shallow water depth, a low velocity blower can be used instead of a large compressor. Total system weight is 1445 lb, transport size is 126 cu. ft. System is transportable in pieces.

Concept V - Fireproof fence boom is easily constructed (such a product was once marketed as Firefence - discontinued due to low demand). Sections should be 2 ft. x 10 ft. (total weight 2-3 lb/ft) for ease of deployment. Fence boom sections can be anchored in shallow water with re-bar rods 3-4 ft. in length. (See notes in Appendix B.1)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN					
Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
6.2 Oil Processing Capacity	10,000 BPD	3000 - IIA & 10,000 - IIB BPD	4,000-5,000 BPD	600-1500 BPD	3200-4400 BPD

Concept I - The Overall Recovery Rate (ORR) of the open incineration barge is expected to be 5000-10,000 BPD. The process should not be limited by the oil supply. Assuming an effective burn area of 25 ft by 150 ft provides a burn capacity of 11,025 BPD (assuming a burn rate of 2.94 BPD and that the calculations for open burning in a fire-resistant boom apply).

Concept II - The ORR of the Concept IIA and IIB designs is 5000 - 10,000 BPD. For Concept IIA, the actual achievable burn rate is unknown, but the goal is to enhance air flow into the burn compartment to provide the equivalent open burn capacity of at least 3,000 BPD (with reduced emissions). For Concept IIB, which uses a state-of-the-art flaring burner system, burn capacities up to 10,000 BPD are possible (assuming a steady supply of oil is available to keep the flare operating).

Concept III - The ORR for the 100 ft and 180 ft version of the HIB incineration barge is approximately 10,000 BPD at a relative speed of 1 knot. The burn capacity, assuming the open area burn rate calculations apply, are 4721 BPD for the 100 ft version (burn area of 1606 ft^2), and 11,907 BPD for the 180 ft version (burn area of 4050 ft^2). Although the 180 ft version provides a higher burn capacity, it is more likely that a modular, transportable unit would be 100 ft in length or less. Hence an oil processing capacity of 4000-5000 BPD is expected.

Concept IV and V - Concepts IV and V are essentially fire-resistant barriers, such that the oil processing capacity can be estimated using procedures developed for determining burn area for standard fire resistant booms (as developed by Allen, 1991b and reprinted in the Exxon Oil Spill Response Field Manual). For Concept IV, a barrier length of 100-150 ft deployed in a U-Configuration provides a burn area of 200-500 ft^2, and a burn capacity of 600-1500 BPD. This assumes, of course, that this much oil can be captured/diverted into the barrier to maintain the necessary oil thickness and support a continuous burn. (More likely, less than 10,000 BPD will be available such that oil will be captured, ignited and burned off as the required oil thickness is achieved.) For Concept V, a 500 ft length of fence boom deployed in a U-Configuration provides a burn area of 1100-1500 ft^2, and a burn capacity of 3200-4,400 BPD.

(See notes in Appendix B.2)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN

Topic	Concept I	Concept II	Concept III	Concept IV	Concept V
6.3 Stability	V.F.	V.F.	V.F.	N/A	N/A

PROLINES Version 6.29 is a PC-based hull-design computer program that performs basic hydrostatic and stability calculations. This software was used to analyze the intact stability of Concepts I-III. Applicable stability criteria for new tank vessels are specified by the Coast Guard, in Navigation and Inspection Circular (NVIC) 4-92 dated 2 April 1992, which states:

“The righting energy should not be less than 10.3 feet-degrees up to 30 degrees of heel and not less than 16.9 feet-degrees up to 40 degrees of heel, or the down flooding angle, if that angle is less than 40 degrees. Additionally, the righting energy between 30 and 40 degrees (or between 30 degrees and the downflooding angle, if that angle is less than 40 degrees should not be less than 5.6 feet-degrees)...... The righting arm at an angle of heel equal to or greater than 30 degrees should be at least 0.66 feet....... The maximum righting arm should occur at an angle of heel preferably exceeding 30 degrees, but not less than 25 degrees...... The initial metacentric height, GMt, should not be less than 0.49 feet.”

Concepts I and II -This barge hull form was analyzed at its normal expected operating displacement of 4,585 tons. This displacement is achieved by filling four of the ten wing tanks with salt water and flooding all five centerline tanks to the waterline. At this displacement, the barge hull form has an actual righting energy of 315 ft-degrees up to 30 degrees of heel and 455 ft-degrees up to 40 degrees of heel. The actual righting energy between 30 degrees and 40 degrees is 140 ft-degrees. The actual righting arm at an angle of heel equal to or greater than 30 degrees is 14 feet. The actual maximum righting arm occurs at 25 degrees. The actual initial metacentric height is 29.1 feet. *In summary, the actual stability of the barge analyzed meets or exceeds all Coast Guard intact stability criteria by a substantial margin.*

Concept III - Stability and seakeeping information for the HIB hull form was obtained from Webster Barnes, Inc. To verify the stability of Concept III, the PROLINES software package was also used to perform the basic intact stability calculations for the 180 ft. version of the HIB hull form as proposed by Webster Barnes. The results of these calculations are shown in Figure B-6.The actual righting energy is 138.5 ft-degrees up to 30 degrees of heel, and 200.5 ft-degrees up to 40 degrees of heel. The actual righting arm energy between 30 and 40 degrees is 62 ft-degrees. For the 180' HIB hull, the value of the initial metacentric height (GMt) is 24.6 ft. *In summary, the 180' HIB hull form appears to be highly stable. As the 100 ft HIB hull form is geometrically similar to the 180 ft version, it is undoubtedly stable as well.*

Concepts IV and V - Hydrodynamic stability is not an issue.

(See notes in Appendix B.3)

SUMMARY EVALUATION MATRIX ENGINEERING DESIGN

Topic	Concept I	Concept II	Concept III	Concept IV	Concept V
6.4 Seakeeping	V.F.	V.F.	V.F.	F	V.F.

Concepts I and II - Six degrees of freedom: roll, pitch, heave, yaw, surge and sway can be measured in model tests and full scale tests. The modified barge (Concepts I and II) would require model tests or full-scale tests to fully characterize ship motions in a seaway. Both of these tests are considered outside the scope of this study. At towing speeds anticipated and considering environmental conditions likely to be encountered in the various scenarios described, seakeeping characteristics should not be a limiting factor. The barge hull form provided by the CG Marine Safety Center represents an existing oceangoing barge that has been approved by the U.S. Coast Guard. Therefore it is assumed to have acceptable seakeeping characteristics. Oceangoing barges of this type often operate in sea states well above those that would be encountered during oil recovery and burning operations (0-3 feet).

Concept III - The HIB skimmer motion is inherently extremely well-damped by the entrained mass of the separation area. In addition, its configuration results in relatively low excitation from the sea surface. These two factors—low excitation and highly damped response—result in a vessel that remains highly stable even in severe sea states. Inevitably, bow slamming is a potential limitation on advance speed when encountering high sea states. This condition is common to any similarly shaped barge.

Concept IV - Seaworthiness for this concept translates to the water depths, current and wind speeds under which it will be deployed. The literature indicates that the system should work well in up to 2 to 6 ft of water, current speeds up to 1.0 knots, and wind speeds up to 10 knots. This covers many river and estuarine scenarios.

Concept V - The fence boom concept can be deployed in water up to 3 feet, and currents up to 1 knot. Higher currents can be dealt with by angling the boom with respect to current flow, until oil is guided into quiescent water near shore.

(See notes in Appendix B.4)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN

Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
6.5 Materials for Fire Resistance	F	V.F.	F	N/A	F.

Concept I and II - Steel as opposed to aluminum is required in the burn area due to its superior ability to withstand the heat generated by the burning oil. A36 structural steel is the most commonly encountered steel used in ship construction. Tests have demonstrated that A36 steel will fail in the range of 1000 deg F (538 deg C) to 1100 deg F (593 deg C) which is well below the maximum 1660 deg F expected during in-situ burning of oil. Certain alloys of iron and chromium are highly resistant to corrosion and oxidation at high temperatures and maintain considerable strength at these temperatures. Certain austenitic stainless steels (e.g. 310 stainless steel) are capable of withstanding temperatures up to 2000 deg F. Due to relatively higher costs however ($2.20/lb), 310 stainless steel would be used only in the area exposed to high temperatures; the rest of the barge may be constructed of A36 structural steel.

For Concept IIA, the combustion chamber and stack and stack assembly would extend all the way down to the water surface, thus providing protection for the center tank walls.

For Concept IIB, the fire resistance of materials is not a major issue as combustion does not occur inside the barge. The barge's hull is protected from flame radiation by use of a water spray behind the flaring burner. This technique is routinely employed in offshore platform applications.

Concept III - For this device, there will be a trade-off between the weight of the hull and its heat resistance. The current HIB hull is made of aluminum which is lighter and more transportable but not suitable for burning. The hull used in burning should be constructed of stainless steel, or at least the center portion that comes in contact with the flame. With appropriate cooling and/or insulation, it may be possible to construct the flotation hull (wing tanks) of aluminum to conserve weight.

Concept IV - Fire resistance is not an issue as the hose is submerged in the burn area.

Concept V - Fire resistance can be augmented by increasing the thickness of the corrugated metal, or simply replacing sections in the burn area at appropriate intervals. Fence boom sections should be relatively inexpensive. Boom layers could be doubled-up in the burn area with the inner layer considered sacrificial.

(See notes in Appendix B.5)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN

Topic	Concept I	Concept II	Concept III	Concept IV	Concept V
6.6 Insulation/Cooling	V.F.	V.F.	V.F.	N/A	N/A

Concepts I-III - Two issues concerning insulation must be addressed: thickness and type of insulation. There are several types of materials or techniques that appear to be feasible for use in Concepts I, II and III. Water cooling is possible using seawater.

Water Cooling: Water can be pumped through a piping network to a series of nozzles that are designed to provide a "sheet" of water over the surface to be cooled. This will absorb and carry away any heat from the fire thus protecting the steel substrate.

Ceramic Tile: Ceramic tile installed with a 4" air gap will provide thermal protection. This will require installation of a double-wall in the burn area.

Starlite: Starlite is a plastic which has been demonstrated to endure spot temperatures of 10,000 deg C. Cladding the burn area of a barge being used for in-situ burning of oil with Starlite should adequately insulate the steel or aluminum from the heat of the fire. However, Starlite is still in the R&D stage. Engineering implementation, fabrication and cost considerations would have to be explored.

TempCoat: is a premixed composite material consisting of 80% microscopic, air-filled ceramic and silicon beads. The unique and superior insulating capacity of TempCoat is the result of air within the hollow glass beads serving as a thermal barrier much like double-paned thermal glass windows. TempCoat is applied much like conventional paint. One coat is approximately 15 mils.

Of the approaches described above, a simple water spray cooling system appears most feasible for Concepts I and III, with the water pumps located on the device for Concept I, and on the tug or trailing barge for Concept III. For Concept IIA, cooling is provided within the incineration device itself, which is isolated from the vessel hull (as described by Glosten *et al.*, 1991). For Concept IIB, the cooling mechanism is provided by the water spray behind the flaring burner.

Concept IV and V - Insulation and cooling are not issues with concepts IV and V.

(See Notes in Appendix B.6)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN

Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
6.7 Ignition Mechanism	F	F	F	V.F.	V.F.

Concepts I, II and III - It will be desirable to have the ability to extinguish and re-ignite the flame at intervals as the supply of oil to the device may be interrupted, or operations may have to be suspended to reposition the device. Three possible ignition systems are envisioned.

Propane Ignition System - A propane jet mounted on the inner wall of the hull (in the burn area) projects a flame at the oil surface when ignition is desired. Several jets would be mounted most likely at the rear of the burn area where the oil will be the thickest. The system is controlled remotely (via telemetry) from the towing/tending vessel.

Diesel Ignition System - This approach is the same as the propane system but uses ordinary diesel oil as the fuel, similar to a burner in a furnace used for home heating. Diesel oil is less hazardous than propane, and a small amount will be sufficient for ignition purposes. *Of all the options, this appears to be the most viable.*

Napalm (Helitorch) System - Such a system would be a shipboard adaptation of the Helitorch. It is possible that this system could be adapted for shipboard use. The major design problems are distributing the napalm over the oil (it is difficult to suspend the distribution system above the flame area without having it be subsequently damaged by the flame) and the general complexity of the system.

Concepts IV and V - Several techniques and devices have been developed for igniting oil inside a barrier or in a pool. These should also be effective for Concepts IV (bubble barrier) and V (metal fence boom). Typical methods used for oil ignition include:

Simple Floating Igniters - These consist of a piece of sorbent material or container with an accelerant which is ignited and allowed to float back into the oil slick. Another variation is a nalgene bottle full of gelled fuel with a marine flare attached (design developed by Spiltec).

Helitorch System - A helicopter slung device that distributes packets of burning gelled fuel. Typical burning globules have a burn time of 4 to 6 minutes.

Although any of these devices is suitable for use with Concepts IV and V, it is most likely that a simple hand-deployed device will be used.

(See Notes in Appendix B.7)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN

Topics	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
6.8 Emissions Control	F	V.F.	N.F.	N.F.	N.F.

Concepts I and II - These two concepts offer the opportunity for employing emissions suppression and control as the burn area is surrounded by a stable platform which can support systems to enhance airflow and increase combustion efficiency. Viable emissions reduction alternatives include integrating a specially designed airflow enhancing combustion chamber into the barge to form Concept IIA, providing systems for dispersing additives (i.e., ferrocene) into the oil, or the use of deck-mounted flaring devices which forms the basis for Concept IIB. Each emissions control measure involves greater complexity and cost. The integration of the enhanced airflow combustion chamber is feasible albeit expensive. A simple ferrocene application system may also be feasible. Incorporating a method for emissions control could allow use of the device inside of the current ISB restriction area (3 miles from shore in most cases).

Concept III - In theory, all of the smoke-suppression techniques and devices suggested for Concept II could be applied to Concept III as well. However, as a practical matter, the desire for a modular, easily transportable device for Concept III will probably preclude machinery-assisted air injection, ferrocene addition, or the use of a flaring burner.

Concepts IV and V - Emissions control is not an issue with these concepts as transporting emissions control equipment (e.g., ferrocene tanks and sprayers) will be prohibited in the remote, shallow-water areas (marshes and tidal creeks) where Concepts IV and V are likely to be applied. In cases where in-situ burning is applied in nearshore areas, the smaller size of the burns, the distance from populated areas, and the immediate benefits of removing the oil will generally outweigh concern about burning emissions.

(See Notes in Appendix B.8)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN

Engineering/Design Considerations	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
6.9 Fire Suppression	V.F.	V.F.	F	F	F

Concepts I, II and III - Fire-suppression/extinguishment equipment serves two purposes. The first is controlled suppression used to regulate the intensity of the burn and resulting heat stress on the hull. The second is complete extinguishment to allow for repositioning of the device, removal of burn residue, and inspection and repair.

Controlled suppression can be achieved by moving out of the oil slick (thereby removing fuel) for Concepts I, IIA and IIB. For Concept IIB, combustion rate is controlled by limiting the flow of oil to the flaring burner. Extinguishment can be accomplished by the same procedures which will allow the fire to burn out over time. However, it may be necessary to provide a procedure or system which will permit immediate extinguishing of the fire in an emergency (e.g., engine failure on the tow vessel or approaching severe weather). To accomplish this, three possible approaches are envisioned.

Water Spray System - This is the simplest system and relies on cooling the burning oil below the ignition point. It requires only a water pump and a system of spray nozzles located on the periphery of the center burn area.
CO2 (or Halon Alternative) System - This system would distribute CO2 into the burn area along the inner wall at the base of the flame. Extinguishment using this system will be far more rapid than with the water spray system.
Foam System - A third option is the use of AFFF or High-Expansion Foam to smother the flame. The foam could be injected directly into the burn area using a distribution system similar to the water spray/CO2 systems or produced by the tow vessels and allowed to drift back into the device. Installation of a foam system on the barge will require additional engineering and expense.

In summary, there are a range of viable options for providing a fire-suppression/extinguishment capability on board the barge/skimmer used in Concepts I-III.

Concept IV - Suppression/extinguishment is best achieved by shutting down the blower which immediately removes the oil concentration barrier and causes the oil slick to spread out such that the thickness falls below the minimum level (2 mm) to support combustion. This must be done with care as the burning oil may drift some distance from the initial burn area. Backup firefighting equipment should be stationed on scene to extinguish secondary fires.

Concept V - The easiest way to suppress or extinguish the burn is to divert the oil from the burn area using a conventional shallow-water boom. The use of AFFF foam should be considered as an emergency backup.

(See Notes in Appendix B.9)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN					
Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
6.10 Oil Residue Capture	V.F.	V.F.	V.F.	F	F

Concepts I, II and III - A mechanism should be provided for removing residue at intervals during the burn to prevent build-up to the point where combustion is hampered. As previous research indicates that some burn residue will remain buoyant, this could be accomplished by installing a gate at the rear of the barge device such that residue can be periodically flushed out and collected by an auxiliary vessel. This will require extinguishing the fire. A system for removing residue during burning could be devised, but the complexity of such a device appears prohibitive. For residues than sink, some means of capturing the oil that sinks to the bottom of the barge should be considered (e.g., a sump).

Concept IV - Removal of residue with the bubble barrier is complicated in that shutting down the barrier to extinguish the fire will also allow the residue to disperse. The best strategy is to allow the fire to burn out with barrier activated, and then remove residue with vacuum hose or dip nets. A secondary, conventional, shallow-water boom can be deployed downstream of the burn area to catch residue both during and after the fire is extinguished.

Concept V - Residue is best removed once the fire is extinguished and residue allowed to cool. Residue can be removed with dip nets, sorbents, or vacuum hoses.

(See Notes in Appendix B.10)

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN					
Engineering/Design Considerations	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
6.11 Time/Cost to Construct	$625K - $1M	A - $1.2M to $1.7M B-$2.12M	$1.17M	$14K (150 ft.)	$10K (500 ft.)

Concepts I and II - Both concepts start with the acquisition of a standard oceangoing barge hull. Fortunately, there are a number of these available at any one time. For this analysis, a base price for the barge hull is estimated at $500,000. The primary unknown is the cost to modify the barge and add ancillary systems. Gross estimate of these costs for Concepts I and II are provided in Table B-3 and B-4 in Appendix B. The cost estimate for modification of an existing barge for Concept I is $123,400; however stainless steel fortification of the hull could cost up to $500K. The cost estimate for modification of an existing barge for Concept IIA is $200K. Fabrication of two enhance air flow combustion units will cost $500K - $1M. Hence, the total cost to produce devices embodied in Concepts I and IIA are roughly $625K-$1M, and $1.2M-$1.7M respectively.

Concept IIB is essentially a barge hull used in Concept I, with a section of decking left intact to support the flaring burner and associated equipment (air compressors, oil pump, water pumps for flame radiation abatement, connecting lines, generators, etc.). The total cost of Concept IIB is assumed to be the barge hull cost ($500,000) + Concept I modification cost ($125,000) + cost of an Expro flaring burner (10,000 BPD capacity) and associated equipment (~ $1,500,000) which equals approximately $2,125,000.

Concept III - The designers and manufacturers of the HIB Skimmer (Webster Barnes, Inc.) were directly consulted to determine the time and cost required to build a scaled-up version of the HIB skimmer hull. As described in Section B.1.3 of Appendix B, they have proposed two scaled-up versions of the HIB for the oil burning application, a 180 ft long version, and a 100 ft long version. The 100 ft. version is most realistic for Concept III. They estimate that the cost of the smaller device would be $710K. Making the designs modular for ease of transport will increase cost by 65%, making the cost of a modular version of Concept III ~ $1.17M.

Concept IV - This system will probably have to be pre-constructed and pre-staged to be available for spill response. The total cost of a system consisting of 150 ft of hose, a hydraulic hose reel, a blower, and a power pack is estimated at $14,000.

Concept V - Corrugated sheet metal is relatively inexpensive (approx $2/sq. ft. or $40 per section). Anchor bolts and re-bar may total another $10-$20. Labor to cut-fabricate- assemble is estimated at one man-hour per section. Cost per section should be in the range of $100 per section or less. A 500 ft kit would cost approximately $10,000.

SUMMARY EVALUATION MATRIX FOR ENGINEERING DESIGN

Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
6.12 Inspection /Certification	F	F	F	N/A	N/A

Concepts I, II and III - The inspection, certification and approval criteria for Concepts I, II and III will probably be determined on a case-by-case basis depending on the ultimate design and configuration of each device. It is possible that Concepts I and II will have to meet some of the requirements of Subchapter D, 46 CFR as they are initially tank vessels, and exceed 500 gross tons, the cutoff for relaxed requirements under the latest Coast Guard OSRV policy directives. It is clear that Concept IIA and IIB will be viewed as hazardous waste incinerators by EPA and will have to meet permitting requirements under 40 CFR 264-265. This may not be the case for Concept I, but this will be subject to EPA interpretation. Concept III may be subject to the Coast Guard OSRV requirements for small or large recovery vessels, depending on the gross tonnage of the device. Concepts I, II and III should meet the requirements for operation in Grade B & C oils. It is also clear that inspection and certification requirements will be greatly simplified if the devices are unmanned during operation. In general, it can be assumed that all of the devices embodied in Concepts I, II and III would be inspected, certified and approved for use.

Concepts IV and V - Inspection/certification of the systems is not required. Use will have to comply with EPA and OSHA criteria for spill response and local air quality regulations.

(See notes in Appendix B.12)

7.0 Evaluating Operational Considerations

In addition to the basic engineering design aspects of the various concepts proposed, it is necessary to consider the requirements for transporting, deploying, tending and monitoring each device/system during the spill response effort. Operational considerations include:

- Transport, assembly and deployment of the device/system to the spill site
- Requirements for tending on scene
- Device/system simplicity and reliability in operation
- Operational safety
- Environmental monitoring requirements
- Cleaning and/or disposal of components
- Refurbishment of the system/device for reuse

The analysis of operational considerations is summarized in the following Summary Evaluation Matrices (7.1 through 7.7). The unabridged analysis (including calculations and discussions) is contained in Appendix B.

The overall feasibility of having each concept meet the various operational requirements and criteria under each topic is expressed using a qualitative feasibility rating. The qualitative rating scheme is as follows:

V.F. Very Feasible (operational criteria can clearly be met; constraints can be overcome)
F Feasible (operational criteria can probably be met; some constraints will require significant effort but can be overcome)
N.F. Not Feasible (operational criteria will be difficult to meet; many constraints will prove intractable)

No numbering

N/A Topic is not applicable to this concept

SUMMARY EVALUATION MATRIX FOR OPERATIONS

Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
7.1 Transport, Assembly and Deployment	F	F	V.F.	V.F.	V.F.

<u>Concepts I and II</u> - The transport, assembly and deployment of the barge devices in Concepts I and II is straightforward albeit time consuming. The devices can only be transported by sea using an oceangoing tug as the tow vessel. The modified barge devices in Concepts I and II can be transported by sea with a maximum tow speed of 7 knots. The assembly time for Concepts I and II assumes that the barge has been fully modified and outfitted prior to reaching the staging area. On-scene assembly and deployment will involve inspection and checking of the various systems that might be included (e.g., CO2 fire-suppression system, ferrocene additive distribution system), rigging of the collection boom outriggers, and rigging the tow lines and secondary collection boom. Once at the spill site, it is assumed that the barge can be ready to begin operation within an hour. Total mobilization, assembly and rigging time is estimated at only 7 hrs. In order to be able to respond to a spill within 36 hrs (i.e., meet USCG Tier II response criteria) the barge can be located no further than 203 NM (nautical miles) from the spill site.

<u>Concept III</u> - The underlying assumption for Concept III is that the device will be modular, that is, it can be broken down in sections amenable to overland transport by truck or by air (e.g., C-130 or

C-5A cargo aircraft) to the staging site. Assembly time at the staging area depends on the final configuration of the device which has not been fully determined at the conceptual design stage. However, it is reasonable to expect that the HIB-like device can be assembled, outfitted and launched within 6-10 hours. Because of the time saved in overland and air transport, this time delay is not of major concern. Once assembled, the device can be towed to the spill site by a tug of appropriate size. Assuming that air transportation is available and that the spill is 20 NM offshore, the device can be stored up to 9,200 NM from the spill site and still meet the Tier II response criteria.

<u>Concepts IV and V</u>- Because Concepts IV and V are comprised of several smaller, easy-to-handle components, many of the loading and transport assumptions used for Concept III with regard to overland and air transport will apply. The devices can be easily loaded on a flatbed truck, or commercial or military cargo plane. Mobilization, assembly, and deployment times will be minimal (perhaps 1- 3 hours). Accordingly, the system components can be stored up to 10,000 miles from the spill site and still meet the Tier II criteria. As the components of Concept IV are relatively inexpensive, systems could be pre-staged at several locations around the country. Concept V could be fabricated as needed, as long as a local source of materials (corrugated metal

and the necessary hardware) has been identified in advance.

(See notes in Appendix C.1)

SUMMARY EVALUATION MATRIX FOR OPERATIONS					
Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
7.2 Tending On Scene	F	F	F	F	V.F.

Concepts I and II - Tending on scene will require the use of towing vessels, and possibly a small auxiliary vessel to check the condition and operation of the barge, remove residue, inspect secondary collection booms, and be available to deal with emergencies. The towing vessels for Concepts I and II will probably be larger offshore tugs or possibly offshore supply vessels, with sufficient horsepower to transport the barge to the scene and sufficient maneuverability to keep the device on station at speeds below 1 knot. This slow speed maneuverability is required to keep the device more or less stationary with respect to a continuous, fixed oil spill source (particularly a blowout), the primary application for which Concepts I and II are designed. As operation of Concepts I and II may require being on station for several days, the towing vessels must have the necessary endurance and crew accommodations to support this.

Effective operation will require that the device be kept in the thickest portion of the oil slick to intercept the maximum quantity of oil. Periodic spotting by aircraft, ideally a helicopter, may be required to locate heaviest concentrations of oil, and assist in positioning the barge. It is expected that operation will be restricted to daylight hours, unless airborne surveillance and the stability of the spill source (in both volume and transport of the slick) allow for night operations.

An auxiliary vessel will be required for checking the condition of the barges, tow lines, and booms; monitoring downwind concentrations of contaminants as required by environmental monitoring protocols; and moving personnel and equipment to and from the towing vessels as necessary. The auxiliary vessel can also serve as an observation platform for officials and media.

Concept III - The tending requirements for Concept III will be very much the same as for Concepts I and II with the exception that the towing vessels need not be as large, as Concept III will be substantially smaller than Concepts I and II. It is also likely that Concept III will be more maneuverable so that it can be actively towed through the oil slick, if necessary, to increase oil encounter rate in the same manner as with fire-resistant booms.

Concepts IV and V - Tending will be limited when the burn is in progress, with personnel in boats or onshore at a safe distance from the burn. For Concept IV, the position of the bubbler hose may have to be adjusted with each tidal cycle to capture oil on the incoming or outgoing tide. For Concept V the condition of the fence boom should be assessed at various intervals. If significant deterioration of the fence boom sections is observed, burning will have to be suspended and these sections replaced. For Concepts IV and V it is assumed that operations will be of shorter duration (perhaps a day or two) and restricted to daylight hours only. Spotter aircraft will be valuable in the initial positioning of the devices, for conducting environmental monitoring, and maintaining site safety and security. Emergency firefighting and fire-suppression teams should be standing by to deal with emergencies.

(See notes in Appendix C.2)

SUMMARY EVALUATION MATRIX FOR OPERATIONS

Topics	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
7.3 Simplicity/Reliability	F	F	F	F	V.F.

Concepts I and II - These devices will vary in simplicity and reliability as a function of the ancillary systems that are used with each device. A simple, no-moving-parts version of either concept will be the most desirable option. Airflow enhancement, onboard ignition, and the addition of emulsion breaking and smoke-suppression additive systems will add complexity as the machinery, hydraulics, and control devices are introduced to support each system. Special provisions will be required to protect machinery and equipment from the heat and flame of the burn itself. In some cases, redundancy of critical systems will be required to ensure reliability. Ancillary systems such as airflow enhancement blowers, aerators in the burn compartment, and emulsion breaker and smoke-suppression distribution systems will achieve higher levels of burn efficiency and environmental protection at the expense of reliability and cost. Probably the most efficient but complex system will be the flaring burner option in Concept IIB, which will require a full suite of supporting generators, pumps, and air compressors, as well as the burner head itself. The complexity of this system will require full-time monitoring of the operation either remotely or perhaps even aboard the barge itself.

Concept III - This device will probably be much simpler than Concepts I and II. The smaller size of the device required for transportability will preclude the addition of large amounts of machinery. The most attractive feature of the HIB skimmer design is its no-moving-parts design which relies on the movement of the device through the water to collect the oil. Ancillary systems for the device will probably be limited to a simple propane ignition system and perhaps passive airflow enhancement. It is expected that this device will be highly reliable.

Concepts IV and V - Reliability is not as important an issue for Concepts IV and V as it is with Concepts I - III, as continuous operation is not anticipated. The auxiliary machinery associated with Concept IV includes a simple power pack and blower which will be highly reliable. As the machinery is located onshore away from the burn, it can be continuously monitored. Concept V is the most simple and reliable system; any fence boom sections that show deterioration can simply be replaced.

See notes in Appendix C.3

SUMMARY EVALUATION MATRIX FOR OPERATIONS

Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
7.4 Operational Safety	V.F.	V.F.	V.F.	F	F

Concepts I - III - The primary safety consideration for employing Concepts I and III is protecting personnel onboard the towing and attending vessels and any vessels that may be in the vicinity of the burn. It is assumed that there are no personnel onboard the burn devices as this will greatly increase the concerns and precautions that must be taken, and in fact may run contrary to current marine safety and worker safety regulations (the only possible exception may be Concept IIB - the flaring burner option).

Positioning of the tow vessel will be a major concern. The tow vessel should remain upwind, and a safe distance away from the burning device, prescribed as five fire diameters away from the center of the burn. A larger concern for the towing vessels is having enough room to maneuver in the event of an emergency, without colliding with the device. In addition to remaining a proper distance from the burn device, the towing vessels must also remain a sufficient distance from the spill source to avoid toxic gases (as with a blowout) and prevent any flashback to the source. Provisions must be made (such as submersion plane) to insure that flame inside the device does not ignite the main slick. A plan must be developed for retrieving the barge if a tow line parts, or a towing vessel experiences an engine or steering casualty. If systems are installed onboard the burn vessels for fire suppression/extinguishment, these should be tested before the burn begins.

Personnel on board the tow vessels must also be mindful of toxic and explosive vapors from the slick itself, particularly when the oil is fresh. Onboard monitoring of toxic and combustible gases is recommended. Protective equipment such as respirators should be available in the event of emergency, but not routinely worn. HAZWOPR training will be required for all personnel along with special training in ISB operations.

Concepts IV and V - Site safety plans for the application of Concepts IV and V will be developed using the NRT guidelines. A Site Safety and Health Supervisor should be designated and personnel involved in the burn operation properly trained (via HAZWOPR training) and fully briefed on the objective and procedures for the burn. The highest risk is posed by uncontrolled spread of the fire to adjacent marsh and shoreline areas. The primary fire-suppression method for the air bubbler approach is to shut down the blower, thus allowing the oil to disperse to the point where the fire goes out. For both Concepts IV and V, firefighting equipment should be available for emergency extinguishing of the fire within the barrier or secondary fires onshore.

Personnel should remain a safe distance from the flame determined to be 5 pool diameters from the edge of the burn. Emergency evacuation equipment and procedures are required. Respirators and protective clothing should be available, but again not worn as a matter of routine. The proximity of nearby residences and commercial facilities should be carefully noted.

(See notes in Appendix C.4)

SUMMARY EVALUATION MATRIX FOR OPERATIONS					
Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
7.5 Environmental Monitoring	V.F.	V.F.	V.F.	V.F.	V.F.

Procedures for environmental monitoring during in-situ burn operations have been established within the ISB Pre-Approval Guidelines for several RRTs and are being finalized at the National Response Team (NRT) level by the Science and Technology Committee (NRT, 1998). These same criteria apply to the five concepts being proposed as alternative approaches to in-situ burning. The main hazard to human populations downwind is the concentration of particulate matter (soot), in the particle size range of 10 microns or less (described as the PM-10 level). The NRT recommends a maximum allowable concentration of 150 micro-grams per cubic meter of PM-10 over an hour. A monitoring program should be instituted in the vicinity of the burn to ensure that these levels are not exceeded.

Concepts I, II and III - The primary environmental consideration is the PM-10 concentration downwind when the burn operation is conducted close enough to shore to be of concern for human populations. The PM-10 concentration can be monitored from an auxiliary boat taking samples along the shoreline, or by monitors located on the shore itself. The major hazards to marine resources are the possible entrapment of marine species in the oil collection boom and the hazard posed by the towing vessels. The aircraft and vessels conducting oil slick surveillance should be mindful of any marine mammals spotted in the area, and the towing vessel - burn vessel maneuvered away from marine mammals as required. Burn residue should not be a problem as it is ideally retained aboard the burn device.

Concepts IV and V - Environmental impact is more of a consideration with Concepts IV and V as these burn operations will be conducted nearshore and onshore, possibly in proximity to human populations in residential and commercial areas and sensitive environmental resources. PM-10 concentrations should be monitored downwind to ensure that the NRT recommended limits are not exceeded. Traffic through sensitive environmental areas to reach the spill site should be minimized with the most benign forms of access utilized (e.g., small boat or helicopter). The impact of heat, noise, and combustion gases on local wildlife populations should be assessed as well as the danger of secondary ignition of surrounding areas. Emergency firefighting equipment should be kept on scene in the event the fire spreads beyond the containment area.

SUMMARY EVALUATION MATRIX FOR OPERATIONS					
Topic	**Concept I**	**Concept II**	**Concept III**	**Concept IV**	**Concept V**
7.6 Cleaning/Disposal	F	F	F	F	F

Once the burn operation has been completed, the devices and equipment for Concepts I through V will have to be demobilized, cleaned, and any oil burn residue and contaminated material properly disposed of according to existing hazardous waste disposal regulations. The level of difficulty associated with this will vary with each concept as described below.

Concepts I and II - The barge devices must be fully cleaned in a shipyard or drydock following use. This will probably be specified in the Coast Guard Certificate of Inspection, as is the usual practice with oil spill recovery vessels which must be gas freed and cleaned after each oil recovery operation. Residual oil will be removed with steam cleaning and detergent with the effluent recovered and disposed of. The cost of this procedure depends on the specific concept employed (I, IIA or IIB) but will be (at a minimum) roughly the same as cleaning and gas freeing a tank barge after it is used to store and transport heavy or emulsified oil recovered during spill response operations ($5,000 - $10,000 for an oceangoing barge).

Concept III - The device described by Concept III will have to be completely cleaned following use, but the modular design and transportability of the device will allow disassembly and transport in sections to a cleaning site. This will preclude the necessity for drydocking and may decrease the cost of cleaning substantially.

Concepts IV and V - The cleaning of the air bubbler system and the fence boom can be accomplished in the same manner as conventional booms, skimmers, and shoreline cleanup equipment. Because the components are small and can be easily handled and transported, they can be transported to a dedicated cleaning facility some distance from the spill site. This may reduce the cost associated with cleaning and disposal of residue and cleaning effluent.

SUMMARY EVALUATION MATRIX FOR OPERATIONS

Topic	Concept I	Concept II	Concept III	Concept IV	Concept V
7.7 Refurbishment	F	F	F	F	N/A

Concepts I and II - The level of refurbishment, and hence the cost, for Concepts I and II will depend on the configuration of the device, the number of ancillary systems (e.g., fire-suppression systems, smoke-suppression additive and emulsion-breaker distribution systems). For Concept I, refurbishment will probably include: inspection of the material and structural integrity; replacement of damaged insulating material; cleaning and repair of distribution lines for CO2, cooling water, and additives; and overhaul and servicing of any machinery onboard (pumps and generators). For Concept IIA, refurbishment will also include overhaul and cleaning of the airflow/burn enhancement equipment (e.g., blowers, air injection systems, and stacks). The refurbishment of Concept IIB will be straightforward including cleaning and gas freeing of the oil containment tank and overhaul and maintenance of the flaring burner system, including burner heads, air compressors, oil and water pumps, and generators. Ideally the flaring burner components can be temporarily removed from the barge hull for servicing. For Concepts I and II, the oil concentration booms will also have to be refurbished or replaced. If there is substantial heat damage or mechanical failures experienced during the burning operation, refurbishment requirements may escalate to the point where a complete overhaul is required. The cost of such an overhaul may be a significant percentage of the initial cost of the device (25% - 50%).

Concept III - Refurbishment of Concept III will require inspection of the burn tank and replacement of any damaged insulation. The flotation hull members will have to be inspected but should be relatively undamaged by the burn; structural integrity will be the key issue after extended service at sea. The modular design will allow disposal of the burn tank if it is heavily damaged, while retaining the flotation hulls and other components for reuse. Refurbishment of the device after extended deployment may cost from 25% to 50% of the original construction cost depending on the severity of damage. The oil concentration booms will also have to be refurbished or replaced.

Concept IV - Portions of the air bubbler system such as the air blower, galvanized chain, and cleanable sections of hose can be refurbished and reused. Damaged sections will be replaced.

Concept V - Sections of the fence boom not subject to heat stress can be reused in several locations during a single response effort. At the conclusion of the response effort, the fence boom will likely be cleaned and disposed of as scrap metal.

8.0 Assessment of Concept Feasibility and Design Characteristics

Based on the analysis of the engineering design and operational considerations for the generalized concepts described in Section 5.0, a preliminary assessment can be made of the overall feasibility of constructing and operating the various devices envisioned. Tables 8-1 through 8-7 present the composite results of the feasibility analysis conducted in Sections 6.0 (Engineering Design) and 7.0 (Operational Considerations) for each of the conceptual designs evaluated. The discussion for each concept 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. Drawings are provided for the designs embodied in Concept I, IIA, IIB, III and IV to give an overview of how each approach might be implemented.

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

Construction of such a device appears very feasible as summarized in Table 8-1. A more detailed conceptual drawing of the device is shown in Figure 8-1. 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 BPD. 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 while allowing oil to flow through. An inclined plane and foil (concepts borrowed from the HIB skimmer) have been added to enhance oil collection, and prevent flashback to the oil slick itself. Outriggers with 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. Manifolds are provided so that the device can be used to burn oil collected by other skimmers.

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 simple CO_2 compressed gas systems controlled remotely by telemetry from the towing vessel (no pumps or complex distribution systems required). Backup fire suppression is provided by AFFF foam released from the tug.

The device can probably be certified by the Coast Guard and EPA as both a barge and incineration device. Because there are no emissions control systems, the device will most likely be restricted to offshore use as with the standard fire-resistant boom approach. The device can be operated in compliance with current site safety and environmental monitoring requirements.

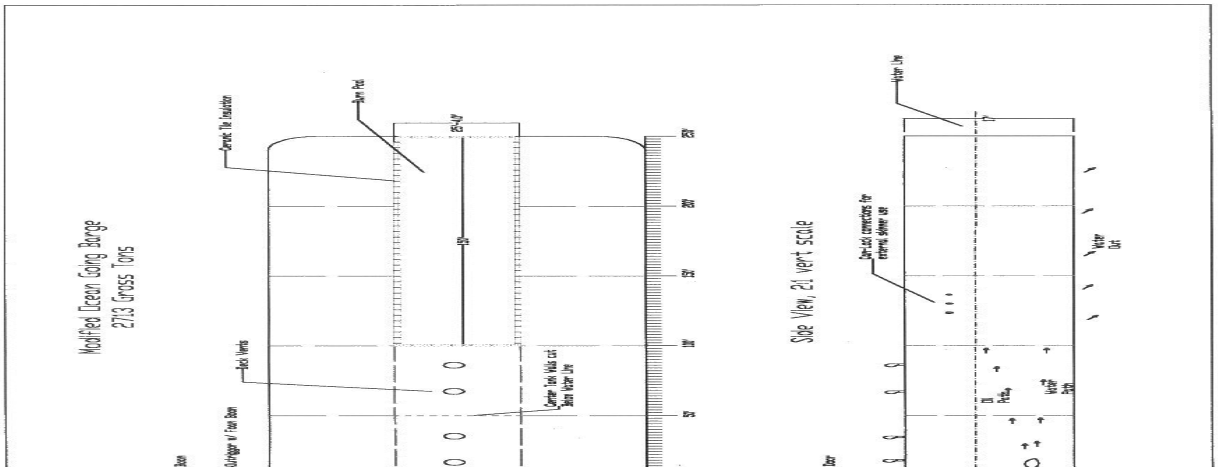
Table 8-1 SUMMARY EVALUATION MATRIX
CONCEPT I - SIMPLE OIL BURNING BARGE

Engineering Design Considerations

Topic	Feasibility	Remarks
Size/Configuration	V.F.	Modified oceangoing barge hull, hull readily available
Oil Burning Capacity BPD	10,000 BPD	Burn area can handle 10,000 BPD if ORR is adequate
Stability	V.F.	Meets USCG criteria, free surface effect minimal
Seakeeping	V.F.	Based on seakeeping characteristics of basic barge hull
Materials/Fire Resistance	F	Stainless steel may be needed for burn area and deck
Insulation/Cooling	V.F.	Simple water cooling scheme for burn area and deck
Ignition Mechanism	F	Simple propane or diesel ignition system
Emissions Control	F	Ferrocene addition feasible but complex and costly -
Fire Suppression	V.F.	Simple CO2 system aboard barge, AFFF from tug
Oil Residue Capture	V.F.	Sump in barge and/or collection port at stern
Time/Cost to Construct	$625K- $1M	Shipyard time 2 weeks - 2 months, adding stainless steel will escalate cost and time to modify
Inspection/Certification	F	USCG certification as OSRV < 500 gross tons EPA certification as incinerator may be required

Operational Considerations

Topic	Feasibility	Remarks
Transport - Deployment	F	By water, must be within 200-250 NM of spill
Tending On Scene	F	Two ocean tugs, auxiliary boat, helo for spotting
Simplicity/Reliability	F	Minimal machinery, simple systems
Operational Safety	V.F.	Safety plan required, no personnel on board
Environ. Monitoring	V.F.	Same as fire-resistant boom burning
Cleaning/Disposal	F	Similar to ocean barge cleaning and gas freeing



Refurbishment	F	Depends on duration of use, level of degradation

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. Such a device would most likely be pre-staged in a central location in an area where there are numerous oil exploration and production platforms (e.g., on the Gulf Coast at Morgan City). The significant advantage of this device over standard fire-resistant boom is its extended service time on scene.

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

Concepts IIA and IB 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 8-2), and the other using a state-of-the-art oil and gas flaring system (shown in Figure 8-3). The engineering and operational feasibility of each is summarized in Tables 8-2 and 8-3 respectively.

Both designs utilize the modified hull form described for Concept I. An existing ocean tank barge hull is obtained and the center tanks removed to allow oil collection and concentration at the stern of the barge. The deck is left in place over the first four center tanks to maintain structural strength. Vents are installed in the deck to prevent buildup of hydrocarbon vapors. Transverse bulkheads are left in place at one foot below the waterline to enhance structural strength while allowing oil to flow through.

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 stacks similar to those investigated at the University of Arizona (Franken *et al*., 1992). Enhanced airflow is supplied 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.

The injected air passing through the angled vanes at the base of the stacks induces a circular motion sometimes referred to as a “fire whirl”. A high velocity circular air motion has been shown to reduce emissions while increasing the burn rate in incinerator systems. The benefit of these vanes is derived more from the circular motion that they induce rather than from the additional air volume supplied.

Ideally, this enhanced air circulation and stack arrangement will provide a 3,000 BPD burn capacity (1,500 BPD for each combustion unit) with reduced emissions (particularly reduction of visible emissions). It should be noted that this technology appears viable but has not yet been fully tested or verified in a large-scale application. A similar combustion enhancement scheme was proposed for an Arctic Incinerator Barge described by Glosten et al. (1991). As with Concept I, a compressed gas propane ignition system would be provided, as would a CO2 fire-suppression/extinguishment system.

Concept IIA can most likely 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 -$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. No combustion takes place within the barge. The current two-burner head model is capable of providing a burn capacity of 10,000 BPD. The burners can handle emulsified oil with up to 50% water content. The emissions produced can be kept well within regulatory limits, with virtually no visible emissions.

Several ancillary systems are required including three compressors to supply atomizing air to the burner head, a submerged 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 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.

Concept IIB can probably 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 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 of the machinery and the projected cost (probably in excess of $2M). Transportability is improved somewhat in that the burner heads and supporting equipment can be moved and transported albeit with some effort (as is routinely done in offshore platform applications). Thus only the barge hulls need to be pre-staged near potential spill sites; the flaring burner system can be centrally located and transported by air.

Table 8-2 SUMMARY EVALUATION MATRIX
CONCEPT II A - OIL BURNING BARGE WITH ENHANCED AIR FLOW COMBUSTION

Engineering Design Considerations		
Topic	**Feasibility**	**Remarks**
Size/Configuration	V.F.	Modified oceangoing barge hull, hull readily available
Oil Burning Capacity BPD	3,000 BPD	Using two air-injection combustion units
Stability	V.F.	Meets USCG criteria, free surface effect minimal
Seakeeping	V.F.	Seakeeping for basic ocean barge is good
Materials/Fire Resistance	V.F.	Combustion units made of stainless steel
Insulation/Cooling	V.F.	Combustion units isolate hull from burning process
Ignition Mechanism	V.F.	Simple propane ignition system
Emissions Control	V.F.	Better air flow improves efficiency
Fire Suppression	V.F.	Simple CO2 onboard
Oil Residue Capture	V.F.	Sump in barge and/or collection port at stern
Time/Cost to Construct	$1.2 -1.7M	Shipyard time 1 - 2 months
Inspection/Certification	F	USCG certification as OSRV < 500 gross tons EPA certification as incinerator undoubtedly required

Operational Considerations		
Topic	**Feasibility**	**Remarks**
Transport - Deployment	F	By water, must be within 200-250 NM of spill
Tending On Scene	F	Two ocean tugs, auxiliary boat, helo for spotting
Simplicity/Reliability	F	Some machinery, more complex systems
Operational Safety	V.F.	Safety plan required, no personnel on board
Environ. Monitoring	V.F.	Monitor stack emissions, possible area monitoring
Cleaning/Disposal	F	Cleaning and gas freeing, more complex than Concept I
Refurbishment	F	Depends on duration of use, level of degradation

Table 8-3 SUMMARY EVALUATION MATRIX
CONCEPT IIB - OIL BURNING BARGE WITH FLARING BURNER

Engineering Design Considerations

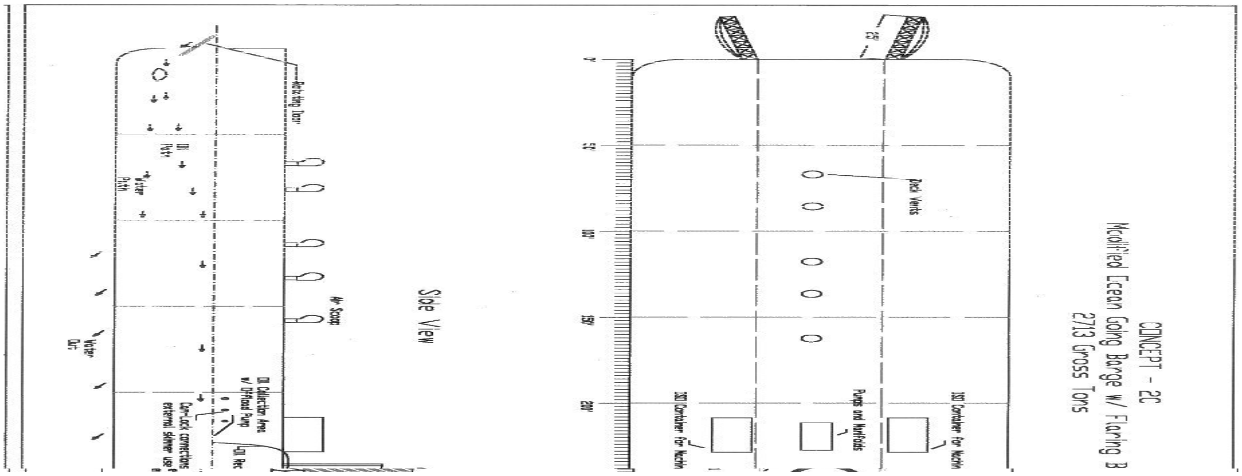
Topic	Feasibility	Remarks
Size/Configuration	V.F.	Modified ocean barge with weir skimmer/pump unit
Oil Burning Capacity BPD	10,000	Not oil limited, two burner heads at 5000 BPD/head
Stability	V.F.	Meets USCG criteria, free surface effect minimal
Seakeeping	V.F.	Based on seakeeping of basic barge hull
Materials/Fire Resistance	V.F.	No combustion in hull, no modifications necessary
Insulation/Cooling	V.F.	No combustion in hull, no modifications necessary
Ignition Mechanism	V.F.	Integral to flaring burner
Emissions Control	V.F.	Provided by flaring burner, no visible emissions
Fire Suppression	V.F.	Regulated through flaring burner, full control
Oil Residue Capture	N/A	Not necessary
Time/Cost to Construct	$2125K	1 - 2 weeks to modify barge, burner system available
Inspection/Certification	F	USCG certification as OSRV < 500 gross tons EPA certification as incinerator required

Operational Considerations

Topic	Feasibility	Remarks
Transport - Deployment	F	By water, barge hull must be within 200-250 NM
Tending On Scene	F	Two ocean tugs, auxiliary boat, helo for spotting
Simplicity/Reliability	F	Flaring burner requires substantial support system
Operational Safety	F	Onboard personnel required, may be a problem
Environ. Monitoring	V.F.	Monitor burner, area monitoring may not be required
Cleaning/Disposal	F	Cleaning and gas freeing of barge

No numbering

Refurbishment	V.F.	Only requires servicing of burner and machinery



8.3 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. Engineering and operational feasibility is summarized in Table 8-4. A simple drawing of the device (180 ft. version) is provided in Figure 8-4.

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 unique system of inclined submersion plane skimmer, flow-enhancing foil, and horizontal baffles to provide a highly 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 CO2 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.

Constructing the 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. Oil collection is accomplished by mounting standard fire-resistant boom (at the bow) and inflatable oil spill boom away from the device to funnel oil into the device.

The designers, Webster Barnes, Inc., have developed an initial hull design for a 180-foot and 100-foot version of the device with oil recovery capabilities of up to 250,000 BPD and 160,000 BPD respectively. Hence the approach is burn capacity limited, but not recovery capacity limited.

The 180-foot model (Concept IIIA) is shown in Figure 8-4. The interior burn areas are 4,102 sq. ft. (146.5 ft. x 28 ft.) for the 180-foot model, and 1,622 sq. ft. (70.5 ft. x 23 ft.) for the 100-foot model. This provides a burn capacity of 11,907 BPD and 4,721 BPD respectively. A modular, air-transportable version of the device will probably be 75-100 ft. in length and have a burn capacity of 4,000 - 5,000 BPD.

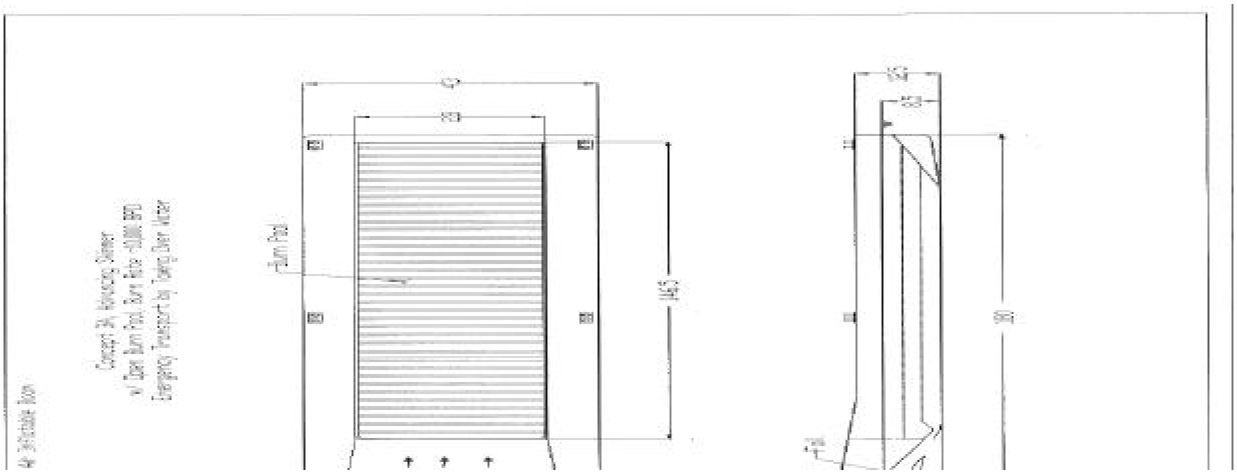
Making the design modular would require some engineering such that the device could be fabricated and assembled in sections. The side flotation hulls could also use a flexible, inflatable design borrowed from technology used to produce collapsible oil storage barges (e.g., the Lancer Barge) and the collapsible oil bladders (e.g., Canflex design). As for cost, Webster Barnes, Inc., estimates that the conventional construction versions of the 180-foot and 100-foot hulls would cost $1,800K and $710K respectively. Converting the 100 ft. version to a modular design would increase the cost of each approximately 65% ($1,171K).

Table 8-4 SUMMARY EVALUATION MATRIX
CONCEPT III - MODULAR, TRANSPORTABLE OIL BURNING BARGE

Engineering Design Considerations

Topic	**Feasibility**	**Remarks**
Size/Configuration	F	Modular hull 75-100 ft long, 25 - 30 ft wide
Oil Burning Capacity BPD	4000-5000 BPD	Depends on size of burn area, burn efficiency
Stability	V.F.	Meets USCG criteria for barge hull
Seakeeping	V.F.	Current HIB hull has low excitation, high damping
Materials/Fire Resistance	F	HIB hull is aluminum, reinforcing/modification needed
Insulation/Cooling	V.F.	Water cooling will be needed for interior hull and deck
Ignition Mechanism	F	Simple propane ignition system
Emissions Control	N.F.	Open burning, no enhanced air flow or additives
Fire Suppression	V.F.	Simple CO2 system
Oil Residue Capture	V.F.	Residue removed via access gate in stern
Time/Cost to Construct	$1170K	$700K for basic HIB hull + 65% for modular design
Inspection/Certification	F	Certify under USCG OSRV guidelines
Operational Considerations		

Topic	**Feasibility**	**Remarks**
Transport - Deployment	V.F.	Design allows air/ground transport, 1000 NM pre-stage
Tending On Scene	F	Towed by two small tugs or auxiliary vessels
Simplicity/Reliability	V.F.	Goal is simple, no-machinery system
Operational Safety	V.F.	More maneuverable than Concept I - II, no personnel
Environ. Monitoring	V.F.	Same as for fire resistant-boom
Cleaning/Disposal	F	Modular design allows disassembly & cleaning off site
Refurbishment	F	Damaged components (e.g. insulation) are replaced



The modular design of Concept III is significant as the system could be flown on cargo aircraft, and transported over the road on a flat bed truck. Table C-1 in Appendix C of this Report estimates that this system could achieve a Tier I Response Time (arrive at the spill site within 12 hours) from a storage site 130 NM away, or achieve a Tier 2 Response Time (arrive within 36 hours) from a storage site 9,200 NM away.

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.

8.4 Concept IV - Air Bubbler System for Shallow Water

Implementation of an air bubbler system for burning spills in shallow water is clearly feasible from an engineering standpoint as summarized in Table 8-5. The system would consist of an air blower (1500 CFM @ 10 psi), a power pack (diesel-driven hydraulic supply to power the blower), 150 feet of flexible bubbler hose weighted with galvanized chain, and a hose reel for ease of transport and deployment. All of these components can be easily acquired or fabricated. Total weight of the system is 2,050 pounds, total volume is 150-200 cu. ft., and total cost is approximately $14,000. The complete system is depicted in Figure 8-5.

Because the system is composed of several components, it can transported by a small truck or helicopter. Transporting the blower by small boat will be difficult; the hose can be transported by small boat if removed from the hose reel and transported in sections. Its deployment and operation are straightforward and will meet current site safety and environmental requirements.

The major questions regarding Concept IV are its effectiveness in wind and currents and the frequency of spill conditions that call for its use. The frequency of application will be addressed more fully in the next section of this report.

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

Concept V is the simplest of all approaches considered. The design remains the same as initially described in Section 5.0.). Each boom section is 2 ft. x 10 ft. (total weight 2-3 lb./ft.) for ease of deployment. The boom is anchored in shallow water with re-bar rods 4-6 feet in length. The total cost of 500 feet of boom is approximately $10,000.

Table 8-5 SUMMARY EVALUATION MATRIX
CONCEPT IV - AIR BUBBLER SYSTEM FOR SHALLOW WATER

Engineering Design Considerations		
Topic	**Feasibility**	**Remarks**
Size/Configuration	V.F.	Modular, 2050 lb., 150-200 cu.ft., 150 ft. of hose
Oil Burning Capacity BPD	600-1500	Open water burn rate, depends on oil encounter rate
Stability	N/A	
Seakeeping	V.F.	System operates well in 3 ft. depth or less
Materials/Fire Resistance	N/A	Hose is submerged, blower located on shore
Insulation/Cooling	N/A	Hose is submerged, blower located on shore
Ignition Mechanism	V.F.	Simple hand-deployed, floating igniters
Emissions Control	N.F.	Open burn
Fire Suppression	F.	Shut down blower, backup firefighting on shore
Oil Residue Capture	F	Dip nets with backup boom to collect residue
Time/Cost to Construct	$14,000	One prime mover/blower unit with 150 ft. of hose
Inspection/Certification	N/A	
Operational Considerations		
Topic	**Feasibility**	**Remarks**
Transport - Deployment	F	Modular design, air/ground transportable

Tending On Scene	F	Minimal, only during deployment and repositioning
Simplicity/Reliability	F	Only machinery is prime mover/blower unit
Operational Safety	F	Personnel on shore, backup firefighting required
Environ. Monitoring	V.F.	Same as fire resistant boom
Cleaning/Disposal	F.	No oil contact, hose contamination should be minimal
Refurbishment	F	Overhaul prime mover/blower, replace damaged hose

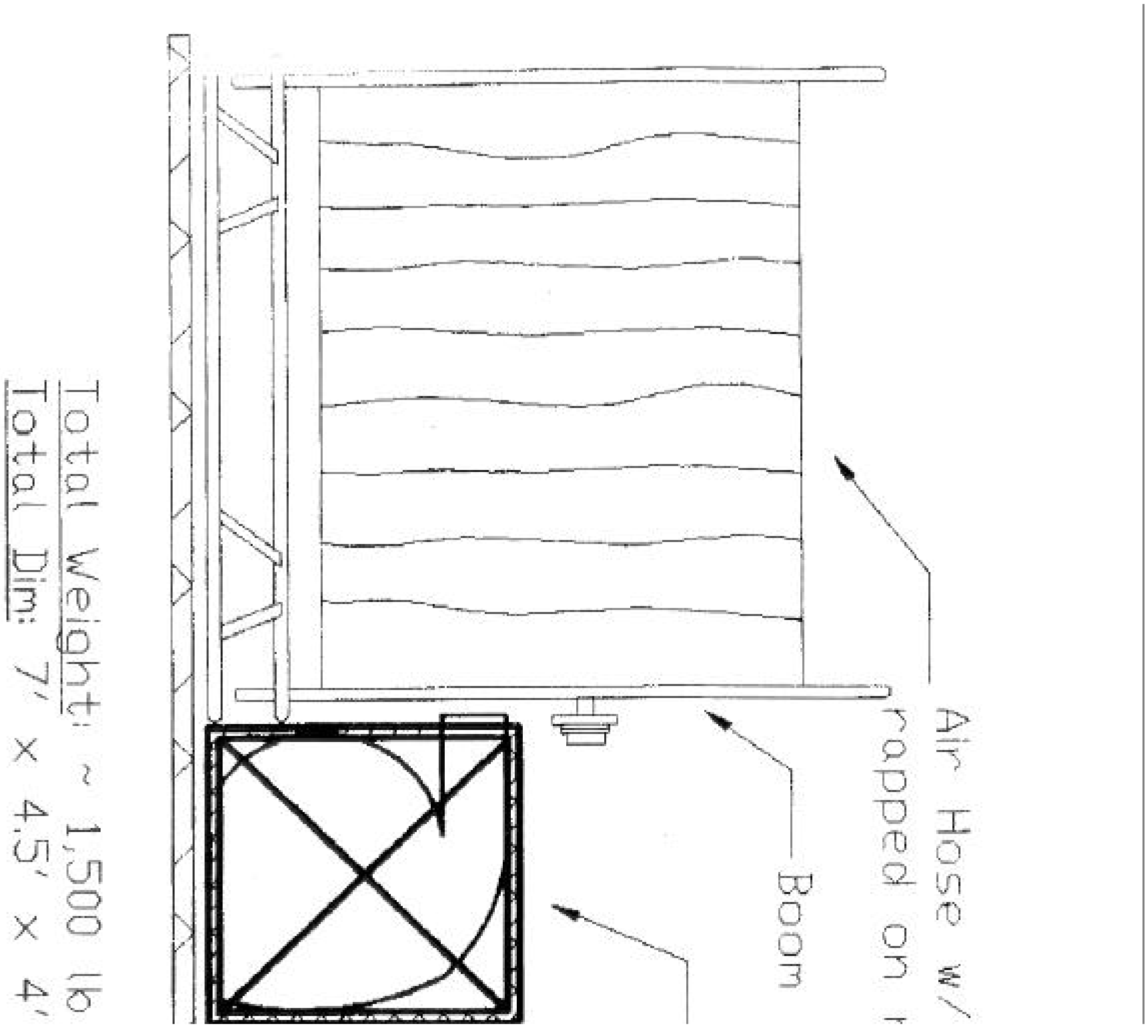


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Table 8-6 SUMMARY EVALUATION MATRIX
CONCEPT V - SIMPLE FIRE-RESISTANT FENCE BOOM

Engineering Design Considerations

Topic	Feasibility	Remarks
Size/Configuration	V.F.	Fence boom in 2 ft. X 10 ft. sections
Oil Burning Capacity BPD	3200 - 4400 BPD	Open water burn rate, depends on oil encounter rate
Stability	N/A	
Seakeeping	F	Can be used in moderate current, up to 1 knot
Materials/Fire Resistance	F	Boom sections are considered expendable/replace
Insulation/Cooling	N/A	
Ignition Mechanism	V.F.	Simple hand-deployed, floating igniters
Emissions Control	N.F.	Open burn
Fire Suppression	F	Divert oil using upstream boom, backup firefighting
Oil Residue Capture	F	Manual removal using dip nets
Time/Cost to Construct	$10K	For 500 ft. fence boom, can be assembled as needed
Inspection/Certification	N/A	

Operational Considerations

Topic	Feasibility	Remarks
Transport - Deployment	V.F.	Easily transported, deployed by two or more people
Tending On Scene	V.F.	Only for section replacement, boom repositioning
Simplicity/Reliability	V.F.	Simplest of all concepts
Operational Safety	F	Personnel at safe distance; backup firefighting required
Environ. Monitoring	V.F.	Same as fire resistant boom
Cleaning/Disposal	F	Use standard boom cleaning techniques
Refurbishment	N/A	Discard/replace damaged sections after use.

The sections are easily transportable by helicopter or small boat to the scene and easily deployed by spill response personnel (from a small boat or perhaps using hip-waders). Deployment and operation are straightforward and will meet current site safety and environmental requirements. The primary question regarding Concept V is the frequency of spill conditions that call for its use. This will be addressed more fully in the next section of this report.

9.0 Applications Hindcast for the Concepts Proposed Based on Past Spills

In Sections 5.0 through 8.0, a number of concepts for alternative approaches to oil spill burning have been proposed, analyzed with respect to the engineering and operational considerations involved in building and using the devices, and further refined and described as prototype designs. It appears that prototypes of the devices described under Concepts I through IV could be further engineered and constructed with additional development and testing. Concept V is straightforward and can be immediately constructed for use.

As an additional step in the evaluation process, the Concepts should be evaluated relevant to their overall applicability in significant past spills to gain some perspective on their contribution to augmenting the currently available suite of technologies and equipment for oil spill response in the future. This analysis is all too often neglected as technologists seek to identify, develop and refine oil spill response technologies. The history of oil spill response technology development clearly shows that funding for research and development is cyclic, with the influx of funding occurring after a particularly alarming event that captures the national interest. Accordingly, RDT&E efforts often focus heavily on solving the specific problems associated with the "last big spill", and overlook the larger need to respond to all major and medium spills that might occur in the future.

History is a good teacher. What follows is a cursory hindcast analysis 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 analysis is based on a number of significant vessel (tanker and barge) and platform spills over the past 30 years. A number of the platform spills were used in developing the design scenarios in Section 4.0. 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 for spills in shallow waters.

For each spill, the important characteristics are identified, the sequence of events summarized, and an assessment made of the applicability of Concepts I - V to the specific spill, or a similar spill with a slightly different set of characteristics. The compilation of spill summaries used in the applications hindcast is presented in Appendix D. Much of the information used was taken from the NOAA HAZMAT compendium of Oil Spill Case Histories - 1967-1991 (NOAA, 1992), and specific papers, most of which are found in the various proceedings volumes from the Biennial International Oil Spill Conferences (1969-1997).

Table 9-1 below summarizes the results of the hindcast. For each spill considered, an assessment is made as to whether the concepts would have been directly applicable if they had been available at the time of the spill - noted as **D/A**, potentially applicable if the same general scenario was encountered but with slightly different circumstances (e.g. more burnable oil, better weather, no explosion and fire) - noted as **P/A**, or simply not applicable to a spill of this nature - noted as **N/A**.

A quick review of Table 9-1 provides the following insight into overall applicability of the concepts proposed. 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, as might be expected given the design scenarios for Concepts I and II. 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, and Persian Gulf), such that they can reach the spill site during the first few days of the spill.

Concept III was directly applicable for 5 spills, and potentially applicable for 5 more. For the spills surveyed, the modular design and air-transportability of Concept III made it potentially applicable for only one additional spill (located in Venezuela where a Concept I or II device might not be pre-staged). However, this underestimates the utility of Concept III in augmenting responses involving mechanical recovery where it can be used as an offshore incineration device for recovered oil (particularly when temporary storage assets are limited, or 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. It was also noted that the documentation of past spills does not generally include detailed information on inshore cleanup such as water depth, current speed, site access, and the tidal flushing of the oil, all of which are important in determining the applicability of Concepts IV and V.

Table 9-1 Results of the Applications Hindcast for Concepts I through V

Spill Name	**Type of Spill**	**Volume** (barrels)	**Concept Applicability**				
			I	**II**	**III**	**IV**	**V**
ALVENUS	Tanker Grounding	65,000	**D/A**	**D/A**	**D/A**	N/A	N/A
AMAZON VENTURE	Valve Malfunction	11,900	N/A	N/A	N/A	N/A	N/A
AMERICAN TRADER	Tanker Grounding	9,458	N/A	N/A	N/A	N/A	N/A
AMOCO CADIZ	Tanker Grounding	1,619,048	N/A	N/A	N/A	N/A	N/A
Apex Barges	Barge Collision	16,476	N/A	N/A	N/A	N/A	**P/A**
ARCO ANCHORAGE	Tanker Grounding	5,690	N/A	N/A	N/A	N/A	N/A
Ashland Oil Spill	Storage Tank Failure	23,810	N/A	N/A	N/A	N/A	**P/A**
ATLANTIC EMPRESS	Tanker collision	unknown	N/A	N/A	N/A	N/A	N/A
BRAER	Tanker Grounding	532,400	N/A	N/A	N/A	N/A	N/A
Brunswick Air Station	Valve Malfunction	1,500	N/A	N/A	N/A	**P/A**	**P/A**
BUFFALO 292	Structural Failure	3,000	N/A	N/A	N/A	N/A	N/A
BURMAH AGATE	Tanker Collision	254,761	N/A	N/A	N/A	N/A	N/A
Chevron MP Block 41	Well Blowout	65,000	**D/A**	**D/A**	**D/A**	N/A	N/A
Colonial Pipeline	Pipeline Leak	13,000	N/A	N/A	N/A	N/A	N/A
Ekofisk Bravo	Well Blowout	202,380	**D/A**	**D/A**	**D/A**	N/A	N/A
ESSO BAYWAY	Tanker Grounding	6,500	N/A	N/A	N/A	**D/A**	**D/A**
Exxon Bayway Refinery	Pipeline Leak	13,500	N/A	N/A	N/A	N/A	N/A
Exxon Pipeline Co.	Pipeline Rupture	2,950	N/A	N/A	N/A	**P/A**	**P/A**
EXXON VALDEZ	Tanker Grounding	292,000	N/A	N/A	N/A	N/A	N/A
Hasbah 6	Well Blowout	100,000	**D/A**	**D/A**	**D/A**	N/A	N/A
Ixtoc I	Well Blowout	3,522,400	**D/A**	**D/A**	**D/A**	N/A	N/A
KIRKI	Structural Failure	135,000	N/A	N/A	N/A	N/A	N/A

No numbering

KURDISTAN	Tanker Breakup	43,900	N/A	N/A	N/A	N/A	N/A
Spill Name	**Type of Spill**	**Volume** (barrels)	**Concept Applicability**				
			I	**II**	**III**	**IV**	**V**
MEGA BORG	Tanker explosion	100,000	**P/A**	**P/A**	**P/A**	N/A	N/A
MORRIS J. BERMAN	Barge Grounding	19,000	N/A	N/A	N/A	N/A	N/A
NESTUCCA	Barge Collision	5,500	N/A	N/A	N/A	**P/A**	**P/A**
NORD PACIFIC	Collision with Dock	15,350	N/A	N/A	N/A	N/A	N/A
Norwuz Oil Field	Platform Casualty	1,900,000	**P/A**	**P/A**	**P/A**	N/A	N/A
PAC BARONESS	Vessel Collision	9,200	N/A	N/A	N/A	N/A	N/A
PRESIDENTE RIVERA	Tanker Grounding	7,310	N/A	N/A	N/A	N/A	N/A
PUERTO RICAN	Tanker Explosion	38,500	N/A	N/A	N/A	N/A	N/A
Santa Barbara Blowout	Well Blowout	100,000	**P/A**	**P/A**	**P/A**	N/A	N/A
Santa Clara River	Pipeline Break	4,600	N/A	N/A	N/A	N/A	N/A
SEA EMPRESS	Tanker Grounding	45,483	N/A	N/A	N/A	N/A	N/A
Shell Oil, Martinez	Facility Leak	9,400	N/A	N/A	N/A	**P/A**	**P/A**
Shell Oil Platform 26	Platform explosion	58,640	**P/A**	**P/A**	**P/A**	N/A	N/A
Tampa Bay Spill	3 Vessel Collision	8,619	N/A	N/A	N/A	N/A	N/A
Trimar Marine Well 327	Well Blowout	36,650	N/A	N/A	**P/A**	N/A	N/A
YUM II/Zapoteca	Well Blowout	58,640	N/A	N/A	N/A	N/A	N/A

10.0 Results of the Expert Panel Review

As a final step in the assessment process, the results of the analysis were reviewed by a panel of government and industry experts in oil spill response technology and operations, and particularly in-situ burning, to solicit guidance on the viability of the proposed concepts, and issues that still needed. As such, this constituted a "reality check" for the study. Preliminary copies of the report were distributed to the following individuals:

Mr. Joseph Mullen, U.S. Minerals Management Service, Herndon, VA
LT Roger LaFerriere, U.S. Coast Guard Headquarters, Washington, DC
Mr. Ken Bitting, U.S. Coast Guard R&D Center, Groton, CT
Dr. Merv Fingas, Environment Canada, Ottawa, Ontario
Mr. Ian Buist, S.L. Ross Environmental Research Ltd., Ottawa, Ontario
Mr. David Dickens, D.F. Dickens Associates, Ltd., Salt Spring Island, B.C.

The reviewers convened in Edmonton, Alberta on June 11, 1998, in conjunction with the 1998 Arctic and Marine Oilspill Program (AMOP) Technical Seminar to discuss the study and offer suggestions and comments. The following is a summary of these comments along with the impact on the final findings of the study.

1)The reviewers questioned the oil encounter rates initially used in the analysis which were based on a slick thickness of 1 mm. It was noted that continuous slicks of this thickness are rarely encountered in responding to spills. It was also noted that the Gas/Oil Ratio (GOR) is an important parameter in determining spill rate and encounter rate , but this was not specified in the design scenarios.

These comments were noted and the encounter rates re-calculated for both 1.0 mm and 0.1 mm spill thicknesses (as shown in Appendix B, Tables B-1 and B-2). It was found that even at 0.1 mm slick thickness, there would be approximately 5000 - 10000 BPD available for recovery assuming a steady source and continuous slick. It is recognized that even this represents and optimum scenario. As for the gas/oil ratio, GOR estimates are rarely provided in the summaries of past oil spills or contingency plan scenarios. Accordingly it is assumed that spill release rates are for pure oil. Again this is somewhat optimistic.

2) The reviewers noted that blowouts often involve dissolution and emulsification of the oil at depth, such that the assumption of easily-burnable, fresh oil at the surface is somewhat optimistic.

This constraint has been noted such that the design scenarios for Concepts I-III represent best case conditions.

3) The reviewers noted that the net heat flux to the barge hull will range from 150-200 MW/m^2

and that temperatures will reach 1600 deg F. This will exceed the heat resistance capacity of standard A-36 steel such that either extensive water cooling or stainless steel fortification of the barge hulls in Concepts I-III will be required. This could substantially increase the cost of Concept I and will require stainless steel construction for Concept III. Even with stainless steel fortification, a water cooling mechanism is recommended to prevent warping of the steel. The deck as well as the interior walls of the burn area must be cooled and insulated due to the radiation from the flame.

This comment has been taken into account in the preliminary designs of Concepts I-III. In particular it has increased the potential cost of Concept I up to $1M. The initial assumption was that Concept I need not be extensively fortified or cooled. This has made Concept I less viable.

4) The reviewers noted that some provision must be made for isolating the oil in the burn area from the main slick to prevent flashback. It was also noted that wave action must be suppressed at the bow so that the burn area remains relatively quiescent.

This flashback issue is addressed for Concepts I and III by including a submersion plane and closing off the bow to prevent ignition of a slick in front of the barge, which will often be 2 mm or more in thickness and hence ignitable. A wave damping mechanism may also be required; this would have to be investigated further if these concepts are carried forward for prototype development.

5) The reviewers questioned the feasibility of additives to break emulsions and suppress smoke. Emulsion breakers are effective but require even distribution and 3/4 - 1 hour to be effective. Ferrocene suppresses smoke but must be mixed with another compound so as not to sink, and is very expensive ($400 per lb. for pure ferrocene). It is not likely that additives will be practical for the large volume of oil to be processed.

The comment was taken into consideration in the final design of Concepts I - III. The addition of additives is not envisioned.

6) Concept IIA initially envisioned the use of passive, enhanced air flow to promote combustion. The reviewers (and specifically Mr. Ian Buist) noted that this is not likely to be effective as 400 % of the stoichiometric air requirement is already available from the surrounding atmosphere. The challenge is evenly distributing the air throughout the burn chamber. This cannot be accomplished with a passive air scoop or air vanes as originally proposed.

A revisit of the literature supports this comment. It is assumed that any air enhancement scheme will require active air input (via blowers) and direct injection as in the Franken et al., (1991) combustion chamber design now incorporated in Concept IIA.

7) The original design for Concept IV called for a 1500 SCFM blower that would supply air to 500 ft. of air bubbler hose. This was based somewhat on the design proposed by Williams and Cooke (1985). Mr. Buist pointed out that the proposed hose length underestimates the air pressure loss in the 500 ft. length of hose. It is unlikely that a blower can deliver air at a pressure that will be sustained along the entire 500 ft. length, such that a compressor will be required. He also pointed out that the weight and volume of the assembly appeared somewhat low.

Consultation with a blower manufacturer (Northern Industrial) and re-calculation of the pressure loss confirms the underestimate of the pressure drop. It is now believed that a 1500 SCFM blower can only deliver air to 125-150 ft. of hose making Concept IV far less attractive. The weight and size of the unit have also been checked and adjusted upward. This has made Concept IV less viable due to the added logistics in transporting and deploying the equipment.

8) The reviewers generally agreed that Concepts I - III would most likely be regarded as incinerators by the EPA, and that obtaining permits may require some effort. They noted the generally conservative position by EPA in evaluating in-situ burning operations in the past. (It was further noted that Concepts I-III may be in conflict with MARPOL Annex V which prohibits incineration at of hazardous materials at sea.)

It is assumed that Concepts I - III will require some form of permit from EPA as outlined in 40 CFR 264-265.

9) The reviewers (and specifically LT Roger LaFerriere) indicated that personnel involved in the operation would require both HAZWOPR and extensive ISB operational training. This training in itself will be costly. It was also confirmed that placing personnel aboard the barges would require significant precautions, and would be prohibited during the burn operation itself.

This comment is noted and will complicate implementation of Concept IIB which may require personnel to be aboard the barge.

11.0 Conclusions and Recommendations for Further Research, Development, Test and Evaluation

Based on the results of the analysis (summarized in Section 8.0) and the comments and suggestions of the review panel, the following overall conclusions and recommendations for further research and development are offered for consideration.

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 $1M 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 and Persian Gulf). Even with this pre-staging, it is unlikely that the barges would be used except for once every 5 - 10 years (as indicated by the analysis in Section 9.0), which will make the cost of maintenance and training prohibitive. Further development of this concept is not recommended.

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. A common disadvantage is the need for pre-staging near the potential spill sites. This is mitigated for Concept IIB as only the barge hull need be pre-staged as the flaring burner system can be transported from a distance at the time of the spill. Hence, of the two systems, Concept IIB is preferred from the standpoint of technological and logistic feasibility. However, as with Concept I, the need for these systems is somewhat infrequent, such that the cost of construction and maintenance appears prohibitive (particularly to any oil company or private spill response company or cooperative). However, 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 - 5000 BPD) 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 is also attractive. A barge hull patterned after the HIB design could be fortified to withstand the heat from the burn by using stainless steel and water cooling. Cooling water could be provided by the towing vessel, or by a pump float towed behind the barge (as with the Coast Guard High Seas Skimming Barrier). It may also possible to provide a pump and weir skimmer assembly that would allow the unit to be converted to a conventional skimmer if the oil became unburnable due to weathering, or burning is prohibited due to the proximity to shore. Because the device is smaller and more maneuverable than the converted oceangoing barge, it can be actively towed though an oil slick. Accordingly, it is recommended that this concept be explored further as a possible alternative for dealing with larger spills from platforms and vessels.

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. In addition, the hindcast analysis in Section 9.0 indicates that the occurrence of spills where such a device might be employed is less than expected, making the cost and logistics involved in constructing such a device questionable. Accordingly, there is no reason to pursue this concept further.

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 connecting each section, and the addition of fire-resistant buoyancy components to the rear of the sections so that the barrier floats with a constant displacement. Refinements to the anchoring scheme will increase ease of deployment. This is a simple design and fabrication project and does not require further R&D. It should also be noted that the barrier is useful for shallow water containment even when burning is not permitted or not desirable.

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Technology Assessment and Concept Evaluation for Alternative Approaches to In-Situ Burning of Oil Spills in the Marine Environment

Appendix A

Assessment of Relevant Technologies

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Appendix A
Assessment of Relevant Technologies

Burning of spilled oil is recognized as an effective method of disposal; however, technical difficulties in burning oil (particularly water-in-oil emulsions) and environmental concerns about smoke and residues have limited its use. Approaches to burning oil spills have varied from direct burning of oil on the water's surface, the surface of ice, or on shorelines (generally described as in-situ burning), to the use of sophisticated devices which involve the collection of the oil and input into the device (e.g. incinerators, flaring burners, and oil burning vessels). Additives have been developed to promote more efficient combustion, break down emulsions so that they can be ignited, and decrease the visible smoke from the burn. Ignition devices have ranged from simple hand held incendiary devices to airborne oil spill ignition systems. This appendix presents a survey of relevant technologies including fire-resistant booms (the standard approach), oil combustion devices and vessels, alternative oil containment and burning barriers, additives to enhance burning and control emissions, and ignition devices to initiate burning. The references cited are contained in Appendix E, the Consolidated References and Bibliography for this report.

A.1 In-Situ Burning with Fire-Resistant Booms

The development of containment booms which allow for the collection of spilled oil and subsequent combustion began in the late 1970s as it became apparent that the technology for the mechanical recovery of oil was far from adequate in dealing with large offshore spills. In order to capture and concentrate oil in a thickness that will allow continuous burning (2mm or more), standard oil containment boom designs were modified to make the booms fire-resistant. This generally involved covering the boom with a fire-resistant fabric, and strengthening the internal structure to withstand both heat and mechanical forces. The term "fire-resistant" is used rather than "fire-proof" as most of these materials will undergo some degradation when subjected to the intense heat and flame associated with in-situ burning.

A number of fire-resistant booms have been developed, tested and marketed over the years. The World Catalog of Oil Spill Cleanup Products currently lists five design that are commercially available (Schulze, 1997). The following is a summary of the current experience in developing and testing these devices, and their use during both experimental and accidental spills, as reflected in the literature. A more complete summary of the state of this technology is provided by Buist *et al.* (1994a).

Allen and Ferek (1993) identified the equipment and practice in using fire booms during an in-situ burn as follows:

> An effective burn at sea would normally involve 300 to 500 feet (92

> to 152 meters) of fire boom; two boom towing vessels (typically 30 to 40 feet, or at least 10 meters in length) with twin propellers, tow posts, and tow lines at least 500 feet (about 152 meters) long; and a means of ignition...The two boom towing vessels would drag the fire boom in a U configuration at approximately three-fourths of a knot or less in order to intercept and hold the oil in the downstream apex of the boom.

This approach to in-situ burning has been employed during several at-sea test burns, and during the EXXON VALDEZ spill in March of 1989. In July 1988, an at-sea test burn was conducted off Spitzbergen with approximately 500 gallons of Statfjord crude oil contained in 300 feet of 3M Fire Boom (Allen, 1991a). This test served as a prelude to the first application of the technology in a major accidental spill. During the EXXON VALDEZ burn, 450 feet of 3M fire boom were towed by two vessels at a speed of approximately 3/4 knot (0.4 m/s) to collect the oil. After one-half hour of oil collection, the oil was ignited and burned during a 75-minute period. During the burn period, the tow vessels maintained a speed of about ½ knot (0.26 m/s). Seas were calm and winds were light. Allen (1991b) described the damage to the boom as follows:

> Inspection of the 3M Fire Boom revealed an expected amount of thermal stress to certain components of the boom, resulting in a slight loss of freeboard and some embrittlement of the fabric between flotation segments. These effects of the burn were not surprising, since the boom used was the last of an earlier boom design. (Modifications to the design and material used in the boom have significantly enhanced the retention of freeboard and the durability of the boom's thermal protection components). The sacrificial PVC covering on the outside of the boom had melted off to the waterline, as it is designed to do. The forward-most leading ends of the boom were still unaffected by the fire, as were the polypropylene towing lines. The boom was in satisfactory condition to be used for additional oil collection and burning operations.

Allen (1991b) estimated that the amount of oil burned was 15,000 to 30,000 gallons in approximately 45 minutes. The residue was approximately 300 gallons, or 2 percent of 15,000 gallons, the lower estimate.

The success encountered at EXXON VALDEZ using in-situ burning, compared to the relative inefficiency of other cleanup technologies in dealing with the spill, prompted a renewed interest in the technique, and additional research and testing in the years following the spill. These efforts culminated in a major at-sea in-situ burning test off Newfoundland in 1993, known as the Newfoundland Offshore Burn Experiment (NOBE). In the NOBE burn, the boom was 700 feet long and consisted of some commercial sections and some experimental sections. The boom was towed at a speed of approximately 0.5 knots. For the first burn, 48.3 m^3 of oil were pumped into the boomed area and ignited. Inspection of the boom after the burn revealed the following:

> Some signs of abrasion were observed in the Nextel ceramic fabric above the waterline between the flotation logs. At these locations, some small gaps in the fabric occurred approximately 10 to 20 cm from the vertical stainless steel stiffeners. Nevertheless, the boom was fit for another burn. (Fingas *et al*., 1995)

For the second burn, 28.9 m^3 of oil were discharged into the boom. Pumping and burning took 1.3 hours; at that point, some pieces of the boom were lost. Again, an inspection was conducted:

> In a prototype section (that included some external tension members near the waterline), the stainless steel wire mesh had parted, allowing two meter-long flotation logs to be released. Analysis of the crystalline structure of the wire mesh after the test revealed embrittlement at the location where the flotation logs had been released.

McCourt *et al*. (1997) summarized the damage to the boom used in NOBE:

> At the end of the first burn, the boom was inspected. Some signs of fatigue in the stainless steel mesh were observed at a point about 10 cm from the vertical stiffeners and some of the refractory fabric was missing; however, the boom was considered fit enough for a second burn. (Environment Canada, 1993)
>
> After the fire had stopped (28.9 m^3 had burned) the boom was again inspected. A prototype section of the boom that incorporated a middle tension member...had lost 3 flotation sections and a number of other sections were completely missing refractory fabric near the vertical stiffeners (Environment Canada, 1993; Raloff, 1993)...Anecdotal accounts from the crew that recovered the burned sections of the boom after the experiment confirmed that the damage to the floats, mesh and refractory fabric of the NOBE boom was severe.

The damage to the fire-resistant boom during the NOBE burn resulted in various refinements to existing boom designs. To remedy this problem, American Marine Inc., in conjunction with 3M engineers, has incorporated higher-temperature-resistant stainless steel mesh surrounding the flotation logs. American Marine Inc. has also included an internal stainless steel cable within the boom to distribute the tension forces (Fingas *et al*., 1995). In addition, several government agencies in the U.S. and Canada (MMS, USCG and Environment Canada) have undertaken additional testing efforts to better define boom performance, and establish a standard protocol for fire-resistant boom tests.

In 1995, additional at-sea tests were conducted to determine the durability and seakeeping characteristics of several, commercially available boom designs. Towing capability tests were conducted by Marine Spill Response Corporation (MSRC), the Texas General Land Office (TGLO) and the Minerals Management Service (MMS) to determine the at-sea towing capabilities of four booms: the Applied Fabric Pyroboom™, the Oil Stop Auto Boom™ Fire Model, TGLO's SeaCurtain™ FireGard™ Oil Containment Boom, and the Navy 3M Fire Boom (Sloan *et al.*, 1995). (Testing was carried out in two phases: the Navy 3M Fire Boom was tested in the first phase in New Jersey and the other three booms were tested in the second phase in Texas.) Dimensions for the booms tested are listed in Table A-1.

Table A-1. Currently Available Fire-resistant Booms Tested by Sloan *et al.*, 1995.

Boom	**Reserve Buoyancy to Weight Ratio**	**Nominal Floatation Chamber Diameter**		**Skirt Draft**		**Freeboard**		**Draft**	
		cm	in	cm	in	cm	in	cm	in
SeaCurtain 27FireGard	2:1	33.02	13	50.8	20	22.86	9	68.58	
Applied Fabric Pyroboom	8:1 40.64	16	58.42	23	34.29	13.5	62.23	24.5	
Oil Stop Auto Boom Fire Model	13.5:1	43.18	17	63.5	25	38.1	15	68.58	27
Navy 3M Fire Boom	5:1	45.72	18	60.96	24	36.83	14.5	69.85	27.5

Performance data were obtained at tow speeds of 0.5, 1.0, and 1.5 knots and speed at boom submergence or skirt surfacing. Freeboard, skirt draft, tow force, and speed at submergence were measured for each boom. Tests, which were conducted in sea state 1, showed that boom freeboard decreased with increasing tow speed for all booms tested. However, none of the booms met the ASTM static freeboard requirement:

> In accordance with the draft ASTM standard for fireproof

> booms...the minimum requirement for static freeboard in open water is 53 cm (21 in). None of the booms tested met this requirement. Rather, most of the booms only met the recommended freeboard for protected water, which is 26 cm (10 in). (Sloan *et al*., 1995)

Skirts, employed to prevent oil from passing under the boom, maintained relatively constant depths. (The exception was the SeaCurtain FireGard, which exhibited a large change in skirt draft when the boom submerged several feet as it was being towed at 1 knot.) The constant depth of the skirt is in contrast to the freeboard of the boom, which decreased with increasing tow speed. If the skirt hung vertically, its draft would be expected to increase with the decreasing freeboard of the boom. Rather than remaining vertical, the skirts angled into or out of the apex of the boom as tow speeds increased. Again, the booms had difficulty meeting the ASTM standard.

The tow speed at which the apex of the boom becomes submerged was also investigated by Sloan *et al*. (1995). They found an exponential relationship between the buoyancy to weight (B/W) ratio and the tow speed at submergence. This led them to recommend a change to the draft standard:

> According to the draft ASTM standard for booms, the recommended required B/W ratio for fire resistant boom is 3:1. If this ratio were to be used as the design criteria for booms, the resulting booms would not be able to be towed above 1 knot, which is below the normally encountered range of towing speeds (up to 1.5 kts) for containment operations. Therefore, a higher B/W ratio should be recommended which would result in booms that could withstand towing speeds of at least 2.0 knots prior to submergence. This B/W ratio would provide reserve buoyancy for wave conformance during containment operations. (Sloan *et al*., 1995)

All booms suffered damage, with deployment and retrieval operations contributing most of the damage. Fire-resistant material was particularly susceptible to tearing. In particular, the Navy 3M Fire Boom was scraped and scratched during launch, leading to the design of a launching container. As the authors point out, however, a boom should be able to withstand normal handling conditions. The Navy 3M Fire Boom also experienced connector failure at the apex of the boom after being towed at 1.5 knots for 10 minutes (Sloan *et al*., 1995).

At-sea boom testing involving the release and burning of oil is expensive and difficult to arrange. To overcome these problems, McCourt *et al*. (1997) designed a system to test booms in controlled settings. Wave tests were performed in a wave flume and burn tests were conducted in an outdoor wave tank using propane instead of burning oil. Tests on a section of boom (the same type of boom used in the Newfoundland Offshore Burn Experiment) resulted in damage to the boom that resembled the damage incurred during NOBE; however, the damage from the test occurred over a longer time period and was not as severe. Based on these tests several modifications to the test protocol were recommended including

1) increasing the heat flux to the boom
2) improving the heat flux measurement
3) increasing the tension to the fire boom during testing; and
4) improving the characterization of the waves near the fire boom during testing.

In 1997, the test protocol was revised and the test tank modified to accommodate these suggested recommended changes. The protocol was exercised using five commercially available boom designs as reported by Walton *et al.* (1998). Overall the test protocol and its application were considered a success although several additional issues were raised and modifications suggested to the protocol.

In summary, it appears that the fire-resistant boom technology has reached a state of maturity. The current challenge to oil spill technology developers is to prolong the service life of the booms during burning operations. Current approaches to this include the refinement of fire-resistant fabrics and boom construction, and the introduction of water cooling into boom design to allow long-duration, continuous burning.

A.2 Oil Spill Combustion Devices

A.2.1 Onshore Oil and Oiled Debris Incinerators

A number of technologies have been designed for burning oil and oiled debris removed from the environment. Technologies discussed below include methods for burning oil, water-in-oil emulsions, oil-contaminated debris, and remediation of natural materials such as sand and gravel. These devices generally consist of a combustion chamber into which the oil and/or oil material is loaded, and a system for supplying forced air to the combustion chamber to accelerate the burning process and reduce emissions. Burn capacities are limited by the size of the devices which are kept small, and often configured as modular component systems, to allow easy transport to the spill site. The primary use of these systems is oiled-debris disposal and the cleaning of contaminated material, although they have been tested with oil and oil/water emulsions.

A.2.1.1 Rotary Kiln Incinerator

Trecan Ltd. undertook tests for Environment Canada of a rotary kiln incinerator's ability to clean oil-contaminated beach materials (Meikle and Ewing, 1980). An existing kiln was modified for the testing. The kiln, which was 6.0 meters long, had an interior diameter of 51 cm. Additions included a auger-type feeder that extended 1 m into the kiln, a 7.6 cm diameter pipe that allowed injection of combustion air at a point 2.0 m upstream of the discharge end, and an orifice and gauge for monitoring the airflow through the pipe. An auxiliary heater was used for preheating the kiln but was not used during the tests. Thermocouples in the kiln and stack provided readings to a strip recorder. Drive speed was adjusted so that the retention time from auger to discharge pipe was 51 minutes.

Two types of sand were used in the test: the first (concrete sand) consisted primarily of small pebbles with some fine sand; the second (brick sand) is more typical of ocean beach sand. Sand was mixed with oil and water and hand fed into the kiln's feeder. Carbon content measurements and visual inspection showed rotary kiln incineration to be an acceptable method of remediation of oiled sand. Feed rates for the two types of sand tested varied from 166 m^3/hr to 479 m^3/hr. Increasing the interior dimensions of the kiln to 2.0 m diameter by 6.0 m long could increase the capacity to 5 to 8 tons/hour (Meikle and Ewing, 1980).

A.2.1.2 Rotary Kiln Combustor

Environment Canada investigated and tested the ability of a rotary kiln combustor to treat oil-contaminated gravel and sorbents (Ouellette and Razbin, 1995). In addition to the rotary kiln combustor, the system included feed systems, afterburner, packed bed spray tower, induced draft fan and stack. Gravel, whether treated with fresh oil, emulsified oil or weathered oil, was found to be oil-free after remediation. Polypropylene sorbents, both those contaminated with emulsified crude in the lab and those collected from a marine spill of Bunker C, were completely consumed in the remediation process. Feed rates of 48 kg/h were obtainable for gravel, while sorbents required a rate of 5.5 to 7 kg/h. Tests results for specific pollutants in flue gasses showed concentrations within applicable guidelines.

A.2.1.3 Trecan Incinerator

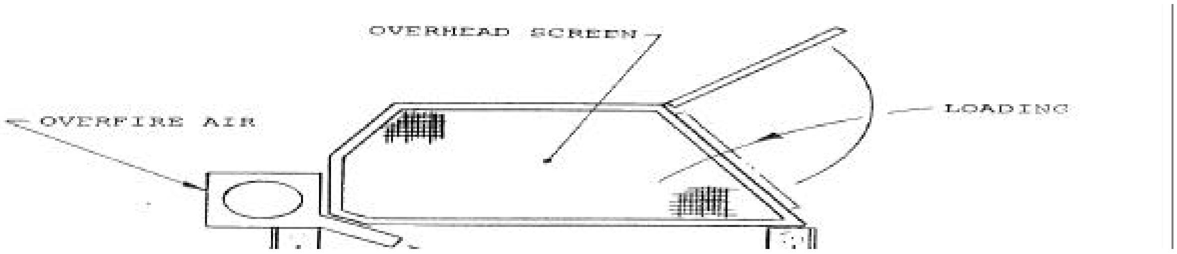
A helicopter-portable pit incinerator designed by Trecan Limited (Lombard, 1979) was developed for disposal of oil soaked debris, but not for oil or emulsions. Air is forced into the incinerator at two points, the top of the combustion chamber and near the bottom of the chamber. The air introduced near the top produces an internal circulation that is intended to eliminate smoke. Air introduced near the bottom aids in combustion of the debris. The design specifications for the incinerator include an incineration rate of 1 ton/hour. The incinerator can be transported (in 14 sections) by medium-duty helicopter.

The unit (Figure A-1) consists of a combustion chamber, an overhead screen assembly, headers, and an engine-blower assembly. Six L-shaped sections form the sides and bottom of the combustion chamber; four additional rectangular sections form the ends. Interior dimensions of the chamber are 5 ft x 10 ft x 5 ft (1.5 m x 3.0 m x 1.5 m). A stainless steel screening assembly placed over the combustion chamber retains lightweight material. Debris is loaded into the chamber through an opening in the screening assembly. A 30-hp 2-cylinder diesel engine drives a centrifugal fan which provides the combustion air. The addition of a loading chute resolved a problem identified during testing. Plans addressing further modifications have been drawn (Lombard, 1979).

In subsequent tests by the Prairie Regional Oil Spill Containment and Recovery Advisory Committee (PROSCARAC), a prototype pit incinerator was used to burn heavy oil and oil sludge (Meikle and Ewing, 1980), although it was not originally designed for this purpose.

A.2.1.4 Air Curtain Pit Incinerator

Disposal of oil, emulsions and oily debris was investigated using an air curtain incinerator (Kruk, 1983) which incorporates a below-ground pit as the combustion area. The pit can be easily


OVERHEAD SCREEN
OVERFIRE AIR
LOADING

excavated near the spill site. While the initial design used a below-ground pit, the author points out that an above-ground chamber could also be used. The air curtain is generated by forcing a large volume of air through a plenum and into a nozzle that runs the length of the plenum along the edge of the pit. Directing the airflow at an angle into the pit causes recirculation which aids in combustion of unburned particulates.

The prototype incinerator used a Driall Air Curtain Destructor® Model ACD-42, modified for testing. The combustion chamber measured 10 feet long by 10 feet wide by 14 feet high; of the 14-foot combustion chamber height, 10 feet were above ground and 4 feet were below ground. The air curtain plenum and air nozzle assembly was located at the top of the combustion chamber; its length was shortened from 42 feet to 10 feet for the test. The angle at which air was introduced was adjusted using an air deflector on the nozzle. The fan, powered by a 75-hp diesel engine, could generate air velocities which would impact the opposite wall of the combustion chamber at 50 mph. The direction of the air at the wall could be changed by tilting the front wall of the combustion chamber, which was hinged at the bottom (Kruk, 1983).

Oil or emulsion could be supplied to the incinerator by two manifolds located in a pan in the bottom of the combustion chamber. The manifold caused the oil to be atomized and sprayed upward into the combustion chamber. Debris could be loaded into the incinerator from a side-mounted chute or from the top. Five-pound bags of oil-soaked straw were used in debris tests (Kruk, 1983).

Testing showed that the addition of air reduced smoke emissions when burning pure oil. Emission levels for emulsions of all proportions were even lower. Debris were incinerated with low emissions, undetectable fly ash, and low flames (Kruk, 1983).

Prototype testing demonstrated an optimal value of 7,000 ft^3/min for airflow, and a system capacity of 20 gallons per minute (685 bbl/day). Airflow should impact the front wall at six feet from the top. Changing the angle of the front wall, which also changed the size of the top opening, produced no improvement in system capabilities. Water sprayed near the top opening of the incineration chamber reduced smoke emissions. When debris was added at a rate of 30 pounds per minute or less, the incinerator was able to dispose of the debris without having it accumulate in the chamber. Side chute loading was found to be hazardous and ineffective (Kruk, 1983).

A.2.2 Oil Burners and Flaring Devices

Several devices have been specifically designed for burning liquid oil and oil/water emulsions derived from oil spill cleanup and offshore oil production operations. Although these devices are somewhat complex in design and require a suite of supporting oil pumps and air compressors, they are very efficient in burning oil while keeping visible emissions at a minimum. Units capable of processing up to 5000 BPD have been designed, constructed, and tested.

A.2.2.1 Rotary Cup Burner (Saacke design)

The Saacke rotary cup burner, which is used in a portable burning system developed and tested by Buist and Vanderkooy (1982), employs centrifugal force to create an oil film that can be atomized. The system consists of three parts: the burner, the control unit and a generator.

> The rotary cup and primary air fan...are mounted on a common shaft. This shaft is driven at high speed (5 000 - 6 300 RPM) by an electric motor. The oil is pumped at low pressure into the conical spilling cup. It is distributed evenly over the cup's inner surface by centrifugal force and thrown off the cup rim in the form of a thin film. Air, supplied by the primary fan, is blown concentrically around the cup and atomizes the oil film...The control unit includes all automatic ignition and shutoff equipment, a screen filter to remove large solids, a gear pump, a 40-kW preheater (optional) and the required valving flow meters and flow controllers. (Buist and Vanderkooy, 1982)

The power source is a 20-kW generator.

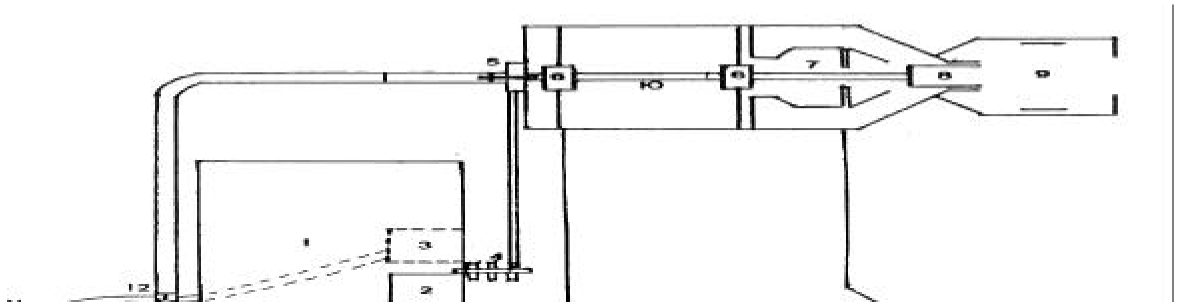
Testing of the prototype resulted in modifications that were incorporated into the final design. When burning emulsions (60% water-in-oil), the system achieved a maximum smokeless burn capacity of 80 m^3/day (500 BPD) in factory test results of the final design (Buist and Vanderkooy, 1982).

The unit was field tested in 1981 in MacKenzie Delta, N.W.T., where 800 m^3 of a mixture of diesel fuel and water were burned in a 30-day period. The system was able to handle a mixture that by volume was approximately 80% water, the maximum encountered (Buist and Vanderkooy, 1982).

Further use at Tuktoyaktuk included disposal of contaminated turbo fuel, mud-contaminated crude, and weathered crude oil and water. A total of 2800 m^3 of waste and slops oil was burned. Although the burner was able to operate at temperatures as low as -20 ^oC, ice crystal formation became a problem in the in-line filter at temperatures below -10 ^oC (Buist and Vanderkooy, 1982).

A.2.2.2 Rotary Cup Burner (Twardus design)

A prototype "Swirlfire" burner based on a design by Mr. Ed Twardus (Energetex Engineering) was developed and tested by S.L. Ross Environmental Research Limited (Buist, 1989). A schematic of the system, which consists of a diesel engine, fan, rotary cup atomizer and combustion head, is shown in Figure A-2. The "Swirlfire" incorporated several improvements over a previous design (Buist and Vanderkooy, 1982). Whereas the previous design supplied



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25% of the stoichiometric air required, the newer system provided 140-150%. In addition to the rotary cup, a second atomization system using impingement of oil on a hot steel plate atomized the oil. A recirculation system within the combustion chamber aided combustion by increasing the residence time inside the chamber. The prototype burner system weighed 400 kg and was designed to be transported by helicopter.

Tests on various types of oil including crude (emulsified and unemulsified), Bunker "C", diesel, and waste engine oil resulted in a nominal maximum combustion rate of 1.6 L/min (14 BPD) for the prototype. When unemulsified crude, diesel fuel, and waste fuel were burned at a flow rate below the maximum reported in the study, the combustion process produced little smoke; however, light smoke was produced when burning Bunker "C', even at flow rates below the maximum suggested (Buist, 1989).

With emulsified crude, the burn rate increased as the water content of the oil increased (up to the maximum water content tested, which was 66%). The presence of water in the oil also increased the length of the flame and changed its appearance. In addition, water droplets were ejected from the combustion chamber and water accumulated in the bottom of the chamber (Buist, 1989).

Suggested modifications to the system are included in the full report (S.L. Ross, 1989). Further tests of the system, recommended by the author, included: burns in an open area where maximum burn rates (ignoring smoke generation) can be determined; longer burns to investigate effects of long-term use of the system; and development of a system with ten times the capacity of the prototype.

A.2.2.3 Coast Guard Flaring Burner

A transportable prototype flaring system that could be used for burning oil at high rates in remote locations was developed for the U.S. Coast Guard by Seaward, International, Inc. (Beach and Goldman, 1981; Beach and Lewis, 1983). The system was designed to be transported by a C-130 aircraft, while individual components were designed to be transported by helicopter.

System components include the burner, supporting boom, oil pump, air compressors, water pump, pilot gas system and hoses and tanks. The burner (John Zink Company, Model OWB-12) consists of 12 nozzle assemblies arranged in a fan-shaped pattern. Each nozzle assembly consists of an oil nozzle, a pilot light and two water nozzles. An 80-foot long boom incorporating oil-, air- and 2 water-supply lines supports the burner. A diesel engine drives the oil pump. Air is supplied by 3 diesel-driven air compressors, which act as counterweights in the burner/boom system. Water, which is used to suppress smoke and thermal radiation, is pumped by a diesel-driven two-stage centrifugal pump. An igniter unit for the pilots and a supply of liquid propane are included in the pilot gas system (Beach and Lewis, 1983).

Light oils were burned at 140 to 150 gallons per minute (4800 - 5140 BPD) with no smoke production when water spray was added. Higher burn rates produced some smoke. Heavier oils burning at lower rates produced smoke (even with the addition of water). Changing to a smaller nozzle and lowering the burn rate (90 gpm) reduced smoke production. Emulsions up to 30% water were successfully burned; higher water content made ignition and burning difficult. Using proper nozzles minimized the problem of fallout for oils up to a viscosity of 870 cs. Water, injected into the oil stream to simulate tank bottoms, doused the flames; the pilot gas system reignited the flames when oil reappeared (Beach and Lewis, 1983).

A.2.2.4 Expro SuperGreen Burner

Disposal of crude oil produced during offshore testing of wells can be accomplished by burning, but the environmental problems caused by oil fallout into the water and air pollution are undesirable. In an effort to overcome these problems, Expro (North Sea) Limited engineers developed a new method for burning crude (Expro Group, 1997).

> A single atomizing head is capable of burning 5,000 barrels of crude oil per day. Atomization is achieved by passing the fluid through a 2.0" diameter chamber. Around the internal diameter of the chamber a series of radially drilled holes are incorporated. These ports allow entry of the atomizing air to the fluid and initial atomization occurs. Due to the positions of these holes, produced fluid exits the chamber at an increased velocity and a vortex is created. This pattern further increases atomization prior to ignition. The 2.0" diameter flow path through the head eliminates the possibility of an atomising chamber becoming plugged with debris and interruptions to flow periods are subsequently eliminated...
>
> Extensive testing of a multiple atomizing head burner assembly was then conducted. The test objectives on this occasion included cleanly disposing of well effluent with flow rates of up to 15,000 barrels per day. During the tests emulsion (60% water) was burnt with only a trace of steam emanating from the burner, and again no fall-out was evident. (Edwards *et al*., undated)

Tests conducted in May/June 1993 (Netherlands offshore), which produced burn rates up to 15,000 barrels per day, were certified by onboard government inspectors as “environmentally acceptable” (Expro Group, 1997).

Tests conducted with the addition of steam to the flame caused the flame color to be almost clear; however, the amount of steam that would be required for high rate tests was deemed to make it impractical (Edwards *et al*., undated).

The ratio of air to crude passing through the burner is critical to successful operation. Air is supplied by compressor, and interruptions in supply can be avoided by using two compressors with a common manifold and running them alternately. The authors recommend three compressors (two under load and one idling) in critical operations such as zero-pollution testing. The quantity of air supplied can be adjusted by using sufficient burner heads to achieve the desired number of barrels per day burned (Expro Group, 1997). Atomizer heads are easily transported and maintained; each weighs less than 20 kg and has no moving parts.

A.2.3 At-Sea Incinerators

The concept of recovering spilled oil at sea and immediately burning it on site using an incineration device has been investigated in detail. A number of devices have been proposed and analyzed, and in some cases exploratory prototypes constructed and tested. To date, a full-scale prototype device has not been built and tested, although this appears to be technologically feasible. The advantage of such a device is the complete removal of the oil under carefully controlled conditions. The major drawbacks are the cost of the device, the limited applications of such a device, and the difficulties in moving the device to spill sites in time to be effective.

A.2.3.1 Pittsburgh Corning Floating Incinerators

Buist *et al*. (1994a) reported on two floating incinerators patented by Pittsburgh Corning. The first, which resembles an inverted funnel, is designed to float partially submerged and to be mounted on supports (fixed location) or moved from place to place. The process is described by Battelle (1979, quoted in Buist *et al*., 1994a):

> Oil residues and emulsions floating on a body of water are burned by confining the layer of residue within a furnace chamber...The furnace is equipped with a combustion air inlet adjacent to the upper surface of the residue and a stack with inlets for combustible gas. The combustible gas burns the combustible material from pyrolysis of the liquid residue to provide a relatively smokeless combustion process.

The second system consists of a vessel that both collects and incinerates the oil:

> A generally U-shaped, buoyant self-propelled vessel...floats partially submerged in a body of water and has a longitudinal channel portion with a front opening. The vessel has an open bottom portion beneath the longitudinal channel portion. As the vessel advances into a body of water, a band of water with the layer of combustible liquid floating thereon enters the channel of the vessel. (Battelle, 1979, quoted in Buist *et al*., 1994a)

As the water moves the length of the vessel, it enters a mixing chamber where,

> ....a monolayer of cellular ceramic nodules are positioned on the top surface of the layer of combustible liquid. The layer of combustible liquid with the nodules floating thereon moves toward the rear...The oil moves into a combustion chamber where it is ignited and burned. The glass nodules...are recycled to the mixing chamber... (Battelle, 1979, quoted in Buist *et al.*, 1994b)

The speed of the vessel, which determines the rate at which oil is collected, is adjusted to match the processing rate, so that "substantially all of the liquid is removed by burning before the band of water passes under the rear or exit portion of the vessel" (Battelle, 1979 quoted in Buist *et al.*, 1994a).

Neither concept was pursued to the prototype and testing phase (Buist *et al.*, 1994a). The processing capacity of such a system was never fully investigated.

A.2.3.2 BP Elijah Burner

Buist *et al*. (1994a), cite Battelle (1979):

> Some of British Petroleum's oil burning investigations were conducted in the late 1960s when the burner called "Elijah" was created. This burner drew oil into a concentrated pool within the lower part of the burner by a vortex-forming, submerged pump. The oil would get several inches thick and was continuously thrown as a spray up into the upper part of the inverted dome-shaped burner in a stream of hot air. The burner, which was 1.5 m wide x 3 m long x 2 m high, consumed about 40 L/hr (6 BPD) in a highly luminous, minimal smoke producing manner. Burning continued even though oil surrounding the burner was substantially less than 2 cm thick. British Petroleum wished to handle 100 tons/hr (15,120 BPD); therefore, this system was abandoned for other physical removal systems. (Battelle, 1979, adapted by Buist *et al.*, 1994b)

A.2.3.3 Acoustic Burner

Acoustic methods can be used to move, collect, and atomize oil to facilitate in-situ burning (Koblanski, 1983). Equipment used includes transducers and high frequency power generators. Three prototypes were designed: the first "herds" oil into a weir where a suction hose can remove the oil; the second combines herding with levitation to collect oil, again into a weir with a suction hose; the third combines herding with atomization and combustion of the oil. A combination of all three types was proposed for use in large oil spills, such as an oil-well blowout. Advantages included: 1) burning of both volatile and non-volatile fractions, eliminating residual sludge; 2) the ability to operate in the presence of waves; and 3) the ability to choose the amount of oil that will be collected and the amount of oil that will be burned.

Subsequent tests reported by Buist *et al*. (1994a) revealed that "the transducer effectiveness was too sensitive to position to be effective in a wave environment and that the oil droplets created were too large (ca. 5 mm) for efficient burning (Lipski 1986, Caron 1988). Incorrectly positioning transducers also rapidly emulsified the oil. Accordingly the concept has never been implemented and tested in a full-scale prototype version.

A.2.3.4 Air Jet Atomizing Burner

Investigations of the ability of a pneumatic jet located near the oil-water interface to atomize oil directly so that it could be burned in situ grew out of work on acoustical methods. Oil sucked into the vertically oriented jet is atomized as it is propelled upward. Water content of the entrained liquid is sensitive to the placement of the nozzle and the thickness of the slick. Buist *et al*. (1994a) reported that previous tests had achieved a maximum oil uptake rate of 1.75 L/min (16 BPD) for one 6 mm diameter nozzle.

Tank tests of a fixed burner with five 6-mm nozzles achieved a burn rate of 5 L/min (45 BPD) when operating parameters were closely controlled. Again, positioning of the nozzle just above the oil/water interface was critical. The burner was consistently able to ignite the slick beneath it, with flames spreading to the surrounding oil slick when slick thickness exceeded 1 to 3 mm (Belore and Seeley, 1990, cited in Buist *et al*., 1994a).

A commercial device incorporating this technology has been developed by Sprayburn Systems Inc. It consists of a single nozzle of adjustable height within a floating burner and contains a propane ignition system (Buist *et al.*, 1994a).

A.2.3.5 University of Arizona Burners

When heated, air and gases tend to rise, developing a rotational circulation as they rise. Following the EXXON VALDEZ spill, a research effort was undertaken by researchers at the University of Arizona to develop an enhanced incineration scheme that utilizes air circulation vanes to induce a circular combustion pattern (known as a “fire whirl”) to increase burn efficiency and suppress smoke (Franken *et al.*, 1992).

The first method of air augmentation involved the use of vanes directed to enhance the rotational circulation. Tests of the passive air vane circulation scheme demonstrated increased burn efficiencies and up to 50% smoke reduction. Modifying the vane shape and placement pattern did not alter the result. In general, the researchers concluded that the use of passive air flow enhancement using vanes was not going to be practical in larger-scale burning applications. Subsequent vane tests by Alaska Clean Seas (ACS, 1991) found vanes to be ineffective.

The second method added air jets, positioned to augment the vane-induced circulation. The use of low-volume compressed air was found to be more effective and practical than high-volume, low-velocity blowers. Burning rates in tests employing compressed air were three and one half times higher than results for vanes alone (Franken *et al*., 1992).

Further tests in the University of Arizona study showed that injection of air in combination with the enhanced natural circulation could further boost burn efficiencies. A prototype incineration chamber/stack device (1.8 m in diameter by 9.8 m high as depicted in Figure A-3) was constructed and tested, demonstrating an average burn rate of 860 BPD, and a peak burn rate of 2,540 BPD. Based on this prototype design, it was postulated that a larger seagoing version of the combustion chamber could achieve a peak burn rate of approximately 4000 BPD, which would be mounted on a standard vessel hull form. The projected cost of such a device (based on a per pound estimate derived from barge construction data of $3.00 per lb. of displacement) was $120,000 (assuming production of 100 units).

A.2.3.6 Arctic Environment Incinerator Barge

Investigating the problem of oil spills in areas of open water and broken ice led to the design of a barge-mounted system (Figure A-4) that incorporated collecting and incinerating oil (Glosten *et al.*, 1991). This fundamental incinerator design investigated by the University of Arizona was incorporated into the design. The barge itself is 144 feet long, 60 feet wide, and has a draft of 11 feet. The displacement of the barge is 890 long tons. The barge envisioned has a skimming capability for collecting oil at one end and transporting the oil into the circular burn chamber (11 m diameter by 10.3 m high) based on the U. of Arizona design, providing a burn capacity of 2100 BPD based on an 11-meter (36-foot) diameter burn area. The barge has a grate and rotating disk assembly that allows it to operate in light broken ice.

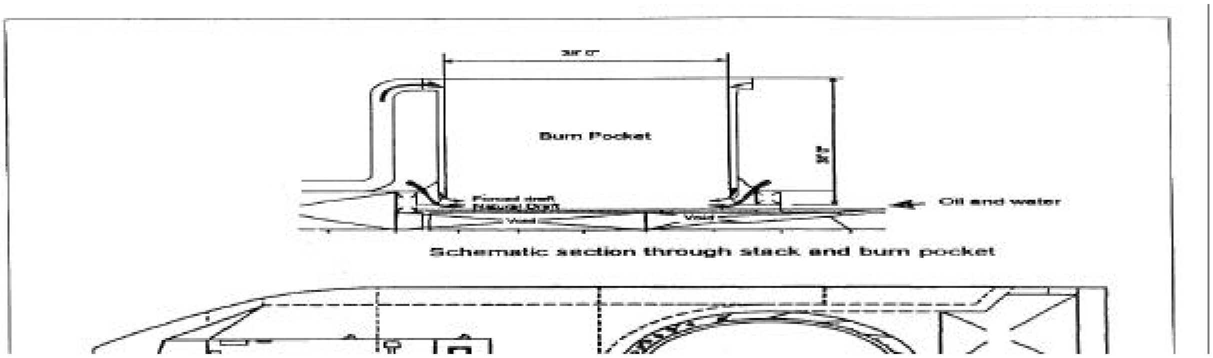
After being towed to the site, the barge would be operated stern-first. Oil encountering the rear of the barge would enter a cylindrical incinerator. The incinerator shell would be double-walled; cool air injected at the top would be preheated as it traveled down the shell. The shell would sit on slanted vanes which would direct the preheated air into the combustion chamber to exploit the concepts of air entrainment advanced by Franken *et al*. (1992). Onboard machinery and support systems include air supply blowers; pumps for oil moving oil and water into the barge, ballasting and cooling water circulation; a helitorch-like ignition system, an ATFF extinguishing system; and generators. The barge would cost approximately $4.15 M to construct.

A.3 Alternative Oil Collection and Concentration Technologies for Burning

In addition to fire-resistant containment booms, several other approaches have been proposed for collecting and concentrating oil at sea to allow for in-situ burning. These include the use of waterjet barriers and air bubbler systems. The advantage to such an approach is that the collection device itself is not in direct contact with the burning oil and thus not damaged. The drawback is the amount of equipment necessary to produce the barrier, the logistics involved in getting this equipment on-scene, and the limitations imposed by wave and current conditions.

A.3.1 Waterjet Barrier

Tests of a prototype waterjet barrier in a 12 m x 15 m x 0.5 m outdoor basin by Environment Canada (Comfort and Punt, 1989) showed that the barrier reduced the opacity of the smoke but also reduced the burn efficiency by causing the formation of emulsions. Tests were conducted with and without the waterjet.



> The operation of the waterjet barrier significantly increased the weight and volume of the residue (in comparison to tests done without the waterjet barrier)...The operation of the waterjet barrier was found to produce turbulence on the water surface and to cause the formation of emulsions. This is believed to be the principal reason for the observed reduction in burn efficiency. (Comfort and Punt, 1989)

The scale of the tests may have created problems. In the tests of the circular waterjet barrier, the diameter of the barrier was 7 m; an oil containment ring of 5 m diameter was located inside the barrier. In some tests, the oil containment ring was left in place; in other tests it was allowed to drop to the bottom of the basin after the oil was ignited and the waterjet barrier was activated. In the contained tests of the circular configuration,

> ...the tests were done on a relatively small scale. For a large burn in the field, the formation of emulsions (produced by the action of the waterjet barrier) is expected to be localized at the perimeter with the result that higher burn efficiencies may be achieved. Thus, the results of this test program may underestimate the burn efficiencies that would be achieved in a field deployment. (Comfort and Punt, 1989)

In the uncontained tests of the circular configuration, some oil that escaped past the waterjet barrier was contained by the basin edge. Surface currents created by the waterjet barrier moved most of the escaped oil back inside the barrier. "It is expected that the oil slick would have been more dispersed in a field deployment and that the burn efficiency would be lowered. This would cause these test results to over predict the burn efficiency that would be achieved in a field deployment" (Comfort and Punt, 1989).

A.3.2 Air Bubbler Systems

Several investigators have proposed the use of submerged, perforated air pipes or hoses to contain burning oil using an air or water generated current barrier (Buist *et al.*, 1994a). Problems inherent in this approach are the machinery requirements for providing high flow rates of compressed air, correctly ballasting and maintaining the hose at an even depth in offshore waves and currents, and the low failure velocity of the air bubble barriers (as low as 0.2 m/s or 0.4 knots).

Williams and Cooke (1985) investigated the use of a porous canvas hose with a blower to provide effective containment without the need for a compressor for water depths of one meter or less, with little or no wind and current. They concluded that an 1000 SCFM blower (at 3 psig) could provide sufficient air to create an air bubble barrier capable of containing burning oil. A somewhat larger blower (weighing 500 lbs) would be capable to supplying oil to a 500 ft. length of hose. They found that the effectiveness of the air bubble barrier increases with increasing submersion depth down to a depth of four feet, and then remains essentially constant. The difficulty with increasing water depth is the additional blower capacity to overcome the hydrostatic pressure at depth. At some point, the use of an air compressor vs. a blower becomes necessary. However, at shallow depths (less than 2 meters), a design such as that proposed by Williams and Cooke (1985) can effectively contain oil and allow it to be burned in quiescent (less than 0.5 knot current) conditions. They further estimated that such a system could be built for roughly $14,000 ($9,000 for the blower and $5,000 for a 500 ft. length of porous hose.

Thus the air bubbler system may be a countermeasure of opportunity in situations involving shallow water and low current flow (perhaps up to 0.5 knots). Further testing in waves and current will be needed to confirm this.

A.4 Additives for Enhanced Burning Efficiency and Emissions Control

A number of chemical additives have been proposed for use in oil burning to improve the rate of burning, allow for the burning of oil/water emulsions, and decrease the level of visible emissions (smoke) often considered a primary drawback to in-situ burning. Viewed in isolation on a smaller scale, each of these additives has proved generally effective. The primary drawbacks in application are the cost and logistics in delivering and distributing the additive over the contained oil (as with in-situ burning in a fire-resistant boom).

A.4.1 Combustion Promoting Additives

Combustion promoters are substances that can be added to a slick to accelerate the burn process and increase the efficiency of the burn. These substances usually act as either a wicking agent or an insulator between the slick and the water substrate or a combination of the two. They are reviewed in some detail by Buist *et al.* (1994a). These substances come in a variety of forms ranging from cellular glass beads (known as Seabeads) which were incorporated into the Pittsburgh Corning incinerator concept (See Section A.2.3.1 above), to chemical powder formulations (e.g. Cab-O-Sil, Aerosil, and Tullanox) which are both wicking and insulating agents, to several expanded perlite (aluminum silicate) products (Fiberperl, Ekoperl and Wonderperl) which are treated with a surface agent to be hydrophobic, and more common materials such as vermiculite, straw, and peat moss. All of these products are effective at enhancing burning to varying degrees. Several have been tested in the field. The primary constraint with their use is the relatively high dosage rate required (often 7 to 10% by weight ratio) which complicates the logistics of distributing the material over a larger spill, and can make treatment of the oil slick expensive and time consuming.

A.4.2 Emulsion Breaking Additives

In a very short time, oil on seawater can become emulsified, with a water content of up to 70% (Bech *et al*., 1993). Emulsification can increase the degree of difficulty in igniting an oil slick and in sustaining the burn.

Igniting an oil slick requires raising the temperature of the surface of the slick above the oil's fire point (Guénette *et al*., 1994). Igniting emulsions can be more difficult than igniting either fresh or weathered crude oil. The two-step process requires creating a water-free oil layer and then igniting the water-free oil. Sustaining the burn requires that water-free oil be generated at a rate equal to or greater than the rate of combustion (Bech *et al*., 1993).

In laboratory tests, adding emulsion breakers to the oil before ignition was the most effective means to enhance ignition, particularly for highly stable emulsions. In field tests, emulsion breakers added to the gelled oil igniters improved ignition and increased the flame spreading rate. "In particular, the use of an emulsion breaker with the gelled oil has proven to be an effective means of igniting otherwise unignitable emulsions using the existing igniter technology (i.e.: Helitorch and gelled gasoline)" (Guénette *et al.*, 1994). Tests of two different ignition breakers demonstrated "firstly, not all emulsion breakers will have the same effect or impact on the ignition of emulsions; and secondly that the emulsion breakers may be oil specific to a certain extent" (Guénette *et al.*, 1994). More recent field tests using a Helitorch-Deployable Emulsion Breaking Igniter EBI (Guenette and Thornborough, 1997) showed the effectiveness of the concept under actual spill conditions to ignite oil contained in a fire-resistant boom.

A.4.3 Smoke Suppression Additives

In-situ burning of spilled oil has met with opposition in part because of the smoke produced. In those open ocean or remote areas where burning of oil in situ is feasible, reducing the smoke production would be desirable. Studies have investigated the ability of various additives to reduce the amount of smoke emitted (Mitchell, 1990; Mitchell and Janssen, 1991; Mitchell and Moir, 1992; Moir *et al*., 1993; Nordvik *et al*., 1995).

Ferrocene, one of the first chemicals investigated, is a non-toxic, organometallic compound that is soluble in hydrocarbon fuels but not soluble in water (Mitchell, 1990). Iron oxide is produced by burning of the ferrocene/fuel mixture. Because iron oxide fouls combustion chambers, ferrocene has had limited use in incineration devices. In direct burning of an oil spill, however, iron oxides are released into the atmosphere; they are non-toxic and are emitted in smaller quantities than soot (Mitchell, 1990).

Ferrocene's ability to reduce soot emissions, even when the amount of ferrocene used was small, has been demonstrated in the laboratory (Mitchell, 1990) and in 1-meter pools (Mitchell and Janssen, 1991). Quantitative laboratory tests and qualitative field tests showed the effectiveness of ferrocene as a smoke inhibitor. In the laboratory, the use of ferrocene produced soot reductions of 60 to 80%; burn rate and burn efficiency were virtually unaffected. In field tests, smoke production was visibly reduced when ferrocene was used. Burn parameters were also affected. The oil with ferrocene required a longer ignition time, which may be related to environmental conditions. The burn with ferrocene was shorter than the burn without ferrocene, resulting in a higher burn rate; it was not possible to determine the burn efficiency accurately (Guénette *et al*., 1994).

Using ferrocene on an oil spill presents difficulties because of its physical properties: it is solid at room temperature, it does not dissolve easily in oil, and its density is greater than the density of seawater. In an attempt to overcome these difficulties, Mitchell investigated other iron compounds (Mitchell, 1990), derivatives of ferrocene (Mitchell and Janssen, 1991), and additives (Moir *et al*., 1993).

Studies of ferrocene and its derivatives led to the investigation of additives that could be used to inhibit smoke emission during in-situ burning. Advantages of these mixtures are their solubility in oil and ability to be added to an oil spill in liquid form (Moir *et al.*, 1993). The most promising additive, RMS-9757, is a liquid that can be sprayed onto the oil spill (Mitchell and Moir, 1992). RMS-9757 was most effective in reducing soot when used at about 2 wt% ferrocene equivalent; however, a treatment rate of about 0.5 wt% was found to be the most cost effective. While alkyl derivatives of ferrocene are thought to be relatively non-toxic, toxicity tests for the additive are planned (Moir *et al.*, 1993).

Using aeration for smoke suppression has been suggested by Nordvik *et al.* (1995). Two methods of supplying additional air to the burn process were tested: an air-jet aeration system and a submerged bubbler system. Use of a fine water spray in conjunction with jet aeration was also investigated. Tests were conducted in a 7.6 m square tank, with a depth of 61 cm.

The air-jet system consisted of a subsurface piping system and five above-water air jets whose height above the slick, orientation and nozzle size could be adjusted. The bubbler system included a network of submerged pipes with holes drilled along the pipes. Air was supplied by two compressors.

Significant decreases in smoke opacity and production were realized with the air-jet aeration system. The system was found to be sensitive to nozzle height, exit velocity of the air jets and wind. (Exit velocity of the air jets is determined by the airflow rate and nozzle exit diameter.) The best results were achieved with a nozzle located 10 cm above the oil surface, with a calculated airflow of 66.3 m^3/min and a nozzle diameter of 3.81 cm, and oriented at a 45° angle to enhance the "fire whirl" effect. Smoke production was described as "most pronounced reduction in smoke of all burns: smoke production reduced to almost zero”. Smoke plume a very thin, very transparent, swirling trail of smoke rising high and diffusing quickly. Almost no wind present during test" (Nordvik *et al.*, 1995). Wind proved to be problematical for the air-jet aeration system because flames could be pushed out of range of some of the nozzles. The addition of water spray did not reduce the smoke production noticeably.

While air-jet aeration was more successful than bubbler aeration in reducing smoke in the absence of wind, bubbler aeration performed more successfully in the presence of wind. Some burns with the bubbler system seemed to increase the amount of smoke; however, the character of the smoke was changed. The smoke produced was lighter in color and remained closer to the ground. The most effective bubbler test resulted in a clear, translucent, diffuse smoke plume of medium gray color, and an immediate increase in smoke when the air was turned off (Nordvik *et al.*, 1995). This burn was also conducted at a slower burn rate, which may be responsible for some of the reduction.

In tests with the air-jet aeration system, burn rate was increased over the baseline burn (without aeration), while bubbler system use "dramatically decreased the burn rate in all cases" (Nordvik *et al*., 1995). Flame temperatures in the most successful jet aeration burn increased from the baseline burn temperatures, while bubbler system temperatures generally decreased.

While their experiments indicated the potential for aeration as a smoke reduction technique, Nordvik *et al*. (1995) recognized the difficulties inherent in at-sea application of the jet aeration system, given its sensitivity to wind. The bubbler system's reduced sensitivity to wind and its ability to reduce the burn rate make it more attractive for potential at-sea use.

A.5 Ignition Devices and Systems

A.5.1 Hand-Held Igniters

Hand-held igniters can consist of relatively simple devices (e.g. a piece of diesel-soaked sorbent material, or a plastic bag filled with gelled gasoline) which can be rigged on-scene to ignite oil contained in a fire-resistant boom, or pooled oil on the shoreline or ice. A similar device consisting of a flare and nalgene bottle filled with gelled gasoline was used with success in field trials off Lowestoft, UK (Guenette and Thornborough, 1997). Such devices are easy to deploy and generally effective.

Other devices are more complex, and have been designed to be air-deployed in remote regions. Two such devices were developed for use in operations in the southern Beaufort Sea (Meikle, 1981). Design considerations for the devices included ability to withstand launch from a fixed-wing aircraft, versatility for use in fresh or salt water, safety, size, weight, cost, longevity when stored, and simplicity of use. The device, when deployed, needs to be able to

> Float freely in 10 centimeters (cm) of fresh water... Heat an area of at least 0.3 m^2 without disturbing the surface or propelling itself away from the area to be heated...Generate heat for at least 2 minutes in sufficient quantity to raise the surface temperature at the boundary of the heated area to at least 100 ^{o}C at ambient air and water temperature of 0 ^{o}C, providing the oil is at least 0.5 cm thick...Provide an ignition source within the oil vapour zone...Permit adequate air supply to the combustion zone. (Meikle, 1981)

The incendiary chosen is similar to "solid propellant for a rocket motor modified to provide a steady, controlled, slow combustion and...a very high flame temperature" (Meikle, 1981).

A sandwich-type design consists of 2 pads of polystyrene foam floatation, one of which contains a delay igniter. Two 6-mm thick layers of plywood separate the foam from a 2.5-cm thick disc of incendiary material. Surrounding the disc of incendiary material is a ring of fast-burning ignition composition. This design will float in less than 5 cm of water and function (even upside down) in shallower water. All parts of the device, with the exception of the firing mechanism, are combustible (Meikle, 1981).

The canister-type design contains an ignition assembly and incendiary composition inside a cone which is surrounded by a honeycomb insert within an outer jacket. Flame and hot gases generated within the canister are directed onto the oil surface by a glass-fibre-filled phenolic dome. The device is designed to float vertically and to scuttle itself at the end of the ignition process (Meikle, 1981).

Prototypes of each design were tested by dropping them from a 10- or 11-meter tower into a basin or pan of water, or onto ice. Air-drop tests from helicopters were also conducted, without the use of oil. Field tests were conducted at McKinley Bay, where drops were made from a helicopter onto ice and into oiled melt pools (Meikle, 1981).

Both designs survived air drops within the design range of speed and altitude, including drops onto ice, and both successfully ignited oil slicks. Preliminary results from field tests indicate high reliability and the ability to ignite oil on melt pools. When water depth prevented the canister design from floating upright, it was still able to function, although less effectively. Modifications to the sandwich design are required to reduce rolling on impact (Meikle, 1981).

A.5.2 Helitorch Ignition System

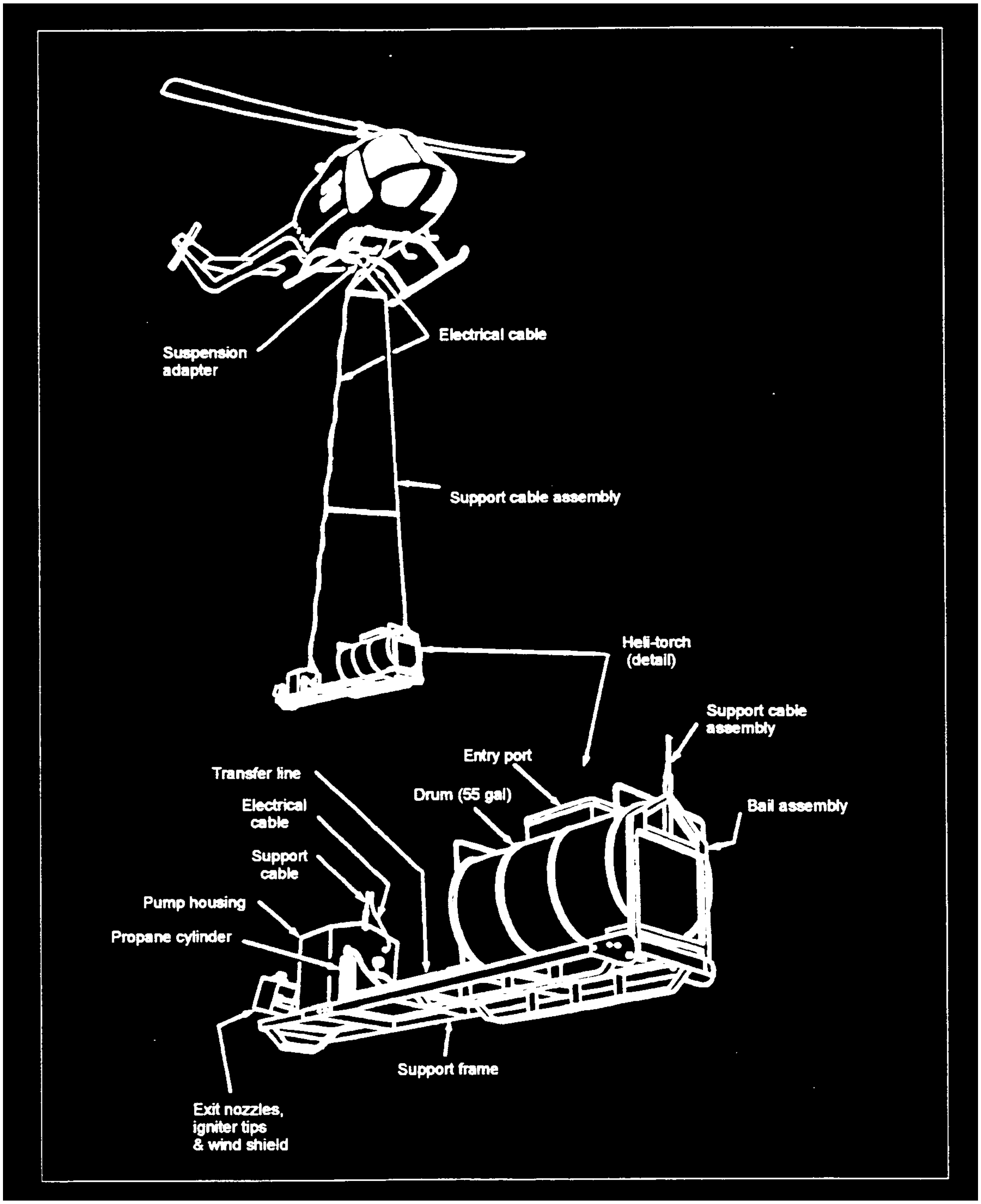
The current system of choice for use in larger in-situ burning operations is the Helitorch system depicted in Figure A-5 (taken from Buist *et al.* 1994a, as adapted from Spiltec, 1996). The Helitorch is a helicopter deployed ignition system manufactured by Simplex manufacturing Company routinely used in burning forest slash and setting backfires during forest fire control operations. It is a completely self-contained unit consisting of a fuel barrel, pump, and motor assembly mounted on a frame, which is slung beneath a helicopter and controlled by an electrical connection to the cockpit. The fuel barrel can be filled with gelled gasoline or gasoline-and-diesel oil mix which is then pumped on demand to a positive-control shut-off valve and ignition tip. The gelled fuel mixture is ignited by electrically-fired propane jets as it exits the distribution nozzle. The burning gelled fuel falls in a highly viscous stream, breaking up into individual globules before hitting the ground.

Technology Assessment and Concept Evaluation for Alternative Approaches to In-Situ Burning of Oil Spills in the Marine Environment

Appendix B

Engineering Design and Construction Considerations -

Detailed Discussion and Calculations


Electrical cable
Suspension adapter
Support cable assembly
Heli-torch (detail)
Support cable assembly
Entry port
Transfer line
Drum (55 gal)
Bail assembly
Electrical cable
Support cable
Pump housing
Propane cylinder
Support frame
Exit nozzles, igniter tips & wind shield

The system was successfully used to ignite oil contained in a fire-resistant boom during the NOBE burn off Newfoundland. More recently, it was used to ignite a test burn off Lowestoft, UK (Guenette and Thornborough, 1997). During these tests, an emulsion breaker was added to the gelled fuel to allow for ignition of emulsified oil. The oil slick was successfully ignited after several passes with the helicopter flying at 20-25 knots and 60-70 feet above the water.

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Appendix B
Engineering Design and Construction Considerations

This appendix provides a more detailed discussion and calculations to support findings on the engineering design and construction feasibility of the various alternative concepts for burning of oil spills outlined in Section 6 of this report. Where appropriate, the findings in Section 6 are annotated to reference specific sections of this appendix which provide the descriptions, calculations, figures or tables to support the overall feasibility rating assigned for a specific issue and specific concept. The references cited are contained in Appendix E.

The calculations in this appendix draw heavily upon previous research and calculations made in investigating and developing the applicable technologies described in Appendix A. A number of approximations and assumptions are made such that the various calculated values should be viewed as reasonable estimates to determine overall concept feasibility, rather than refined design specifications. The calculation of such design specifications is well beyond the scope of this study.

B.1 Overall Size/Configuration

B.1.1 and B.1.2 Concepts I and II

The overall size and configuration of the barges which are used in Concepts I and II are primarily determined by the need to create a burn area ("burn pool") large enough to process roughly 5,000-10,000 barrels per day (BPD) of oil, and the availability of barges that can be modified to provide such a burn pool for this purpose.

The fundamental parameter which determines the size of the burn area required to burn a given quantity of oil is the burn rate, which can be expressed in millimeters (of slick thickness) of oil per minute. This burn rate varies as a function of oil type, ranging from 1.6 to 3.3 mm/min for various crude oils, and 2.9 to 4.5 mm/min for various refined products (Buist *et al.*, 1994a). Typical values are 3.5 mm/min for crude oil and 4.0 mm/min for refined products. *These convert to 2.94 BPD/ft^2 for crude oil and 3.36 BPD/ft^2 for refined products respectively.*

To achieve the desired burn capacity of 5,000-10,000 BPD for the device thus requires a burn area of 1,700 - 3400 ft^2 for crude oil spills. To conform to the typical dimensions of a barge, the length to width of the burn area should be roughly between 3 to 1 and 5 to 1 . The assumption used in developing Concepts I and II is that an existing barge hull will be modified to produce the device envisioned. It is also assumed that the modification would involve opening up the center tank and leaving the wing tanks intact to provide the necessary hydrodynamic stability.

Barges come in several standard sizes. A 1,769 gross ton (GT) Inland Waterway Barge would permit a suitable burn area. (Principal dimensions are : L=300 ft., B=54 ft., T=9.6 ft., D=13 ft.) However this barge does not lend itself to the modification proposed for Concepts I and II (opening up the center tank) as there are only two tanks in the athwartships axis such that there is no center tank to remove.

A more likely candidate is the 2,713 GT Oceangoing Barge. Its principal dimensions are: L=250 ft., B=76 ft., T=7 ft., D=10 ft. The general layout of the barge is shown in Figure B-1. *By opening up the after three of the center tanks, a burn area of 25 ft by 150 ft could be created (3750 ft^2) which, using the assumed burn rate of 2.94 BPD/ft^2 for crude oil, would allow burning of approximately 10,000 BPD.*

B.1.3 Concept III

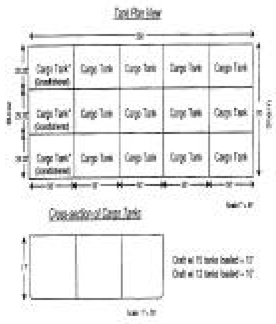
Several ideas were explored in determining the overall size and configuration of Concept III which consists of a modular, easily-transportable hull form that collects and burns the oil in a single operation. One design investigated involved using a standard ISO (International Standards Organization) container to provide the incineration area (burn pool) supported by modular flotation members. However, initial calculations indicated that the burn area would not be adequate, and the device would require extensive modifications such that it would be easier to design and build the device from scratch.

Fortunately, a hull form was identified which closely matches the general size and shape of the device envisioned for Concept III. This device is the Hydrodynamic Induction Bow (HIB) Skimmer designed by Webster-Barnes, Inc. and currently available from Hyde Products, Inc. The HIB skimmer is a versatile, high speed (up to five knots and above) oil concentrating device. A schematic of the device is shown in Figure B-2. The device employs an enhanced submersion plane technology which uses the relative motion of the fluid and the device (either towed or held stationary in a current) to force the oil/water mixture down the bow and into the separation tank. Baffled decks in the tank (in this case the burn area) slow the movement of the mixture, allowing the oil to form a thick layer on the surface while the water exits through vents in the bottom of the device. In the conventional operating mode as a skimmer, the device is outfitted with an offloading pump for oil removal.

A unique feature of the device is the HIB Foil which smooths water flow through the bow and suppresses bow wave formation. This foil allows operation in relative currents up to and exceeding five knots. Effective design features in Concept III (the submersion plane, baffles to enhance oil separation, and the HIB foil) could be incorporated into Concepts I and II as well to enhance oil collection and provide a sufficient slick thickness to support burning. The submersion plane will also prevent premature ignition of oil concentrated in the boom in front of the device.

Implementing Concept III would require scaling up the design to provide a burn area of sufficient size, choosing materials and/or insulating the device to withstand the heat from the fire, and possibly incorporating a modular design scheme to allow transport in sections and assembly on scene. The largest HIB currently available is only 28.0 ft long and 11.4 ft wide with a draft of 2.5

ft. The current maximum oil encounter rate is 142 bbl per hour (for a slick thickness of 1 mm at the shimmer opening) or 3,408 BPD. However, the current tank area (170 ft^2) would support only about 500 BPD of oil burned, assuming the device could withstand the heat (which is



*Barges that are grandfathered with regard to loading regulations may carry cargo in all fifteen tanks. Otherwise, the bow tanks must be used as a rake and remain empty.

Cross section showing flow

FAMILY OF HIB SKIMMER DESIGNS

The oil skimmers designed by Webster Barnes, Inc. constitute a family of skimmers all based on the same design philosophy and operating on the same principals. The foundation of each design is the combination of the proven Submersion Plane and the HIB foil technology. Each product in the HIB family includes an integral oil/water separator and is designed to be best suited to a broad range of applications and environments. A feature of larger models are the stowable pontoons for transport or compact shipboard storage. HIB skimmers are constructed of all welded, un-coated marine grade aluminum for low maintenance and high reliability.

questionable as the current version has an aluminum hull). It should be noted that the HIB R28 design includes fold-up wing tanks which make the device transportable by truck. In determining how the size and configuration of the HIB skimmer could be scaled up to accommodate oil burning in the device, the designers of the device, Webster Barnes, Inc., were consulted and were kind enough to provide conceptual design information. As with the current design, the HIB Skimmer for this application would essentially be a pair of wing tanks joined forward and aft by typical raked bow and transom. The foil and entrance scoop would be situated at the lower end of the bow rake. The central separation area would contain a series of horizontal baffles and supporting structure.

Two units were conceptually described by the designers: a 180 ft length over all (LOA) unit, which has the full required burn area; and a 100 ft LOA unit, which would be easier to handle and more transportable. Both units are within the efficient size range for the HIB skimmer. The nature of the skimmer is such that length and length-to-beam ratio (L/B) are quite flexible. The general characteristics of the two scaled-up devices envisioned (as estimated by Webster-Barnes, Inc) are provided below.

CHARACTERISTIC	**180 ft LOA**	**100 ft LOA**
Length Overall, ft:	180	100
Beam, ft:	43	35
Depth, ft:	12.5	11
Draft, ft:	8.5	7.0
Pontoon Beam, ft:	7.5	6.0
Displacement, LT:	516	198
Burn Area, ft^2:	4,050	1,606

With the burn areas specified above for the 180 ft LOA and 100 ft LOA versions of the HIB skimmer, burn capacities of 4722 BPD and 11,907 BPD would be attainable. *Of these two devices, it is more likely that the 100 ft. version could be designed and constructed in sections for ease of transport. This would still provide a burn capacity of roughly 5,000 BPD.*

B.1.4 Concept IV

The most promising design for a bubble barrier investigated to date is the air bubble barrier proposed and evaluated by Williams and Cooke (1985). The system proposed for Concept IV is essentially a scaled-down adaptation of their design.

As reported by Willaims and Cooke, such a system can be assembled using a lightweight air blower rather than a compressor, which provides air to a 4 in. diameter porous canvas hose either at the surface of the water, or submerged below the surface. They calculated that an 800-1000 SCFM (4psi to 3psi respectively) blower could be used to supply air to a 500 ft. long bubble barrier. Such a barrier could be placed at a depth of 1 ft. below the surface and deeper to generate horizontal water currents of 0.9 to 1.2 knots at the surface. (At depths shallower than 4 ft. the horizontal velocity is decreased in that the air bubble stream does not reach terminal velocity before reaching the surface; at depths less than 1 ft. the effect is dramatic) They further showed that such a current could contain a 5mm to 10mm oil slick in an advancing current of up to 0.5 knots. At advancing currents above 1.0 knot, the slick of this thickness will be advected through the barrier.

There are two fundamental design considerations which dictate the overall size of the system. The first is the need for an air delivery system with sufficient power and capacity to deliver air at the desired flow rate and pressure throughout the length of the hose. The second is the desire to control the weight and volume of the system to allow for ease of transport and deployment.

According to Williams and Cooke, a high capacity blower, capable of delivering 2 to 5 SCFM per foot of hose, is required to provide the necessary air flow to achieve a 1.0 - 1.5 knot barrier generated current at the surface. The pressure at which the air is delivered must be sufficient to overcome the hydrostatic pressure at depth, and the pressure drop in the hose itself which can be substantial. This pressure drop increases with flow rate and hose diamter. A conservative estimate of the pressure drop is 5 - 8 psi per 100 ft of hose. (The pressure drop per length of hose increases as the hose diameter decreases.)

This suggests that a blower with a capacity of 800-1000 SCFM (at 5 - 10 psi) will only support a length of hose of roughly 100 -150 ft. Longer hose lengths will probably require an air compressor, which will add substantially to the size and weight of the system. The hose (4 in. diameter) along with the galvanized chain sinker to keep it submerged when filled with air, will weigh roughly 6 lb/ft. or 600 lb for the 100 ft. length of hose. *With a hose reel (200 lb.) and the motor/blower package (500 lb), the entire system will weigh roughly 2050 lb., and have a volume of 150 - 200 cu. ft.* The system will be modular so that it can be transported to the spill site in sections. For ease of transport to remote areas, it will be advisable to fabricate the hose in 20-25 ft. sections (weighing 120-150 lb. each), so that they can be transported separately if required.

B.1.5 Concept V

Fire-resistant fence boom is easily constructed; a commercial version of a stainless steel, fire-resistant fence boom is currently marketed by Spil-Tain, Inc of Tacoma, WA (Schulze, 1997). *A less expensive version for stationary deployment in shallow water would be fabricated of corrugated sheet metal. Sections should be 2 ft x 10 ft (total weight 2-3 lb./ft. or 20-30 ft. per section) for ease of deployment.* Boom can be anchored in shallow water with re-bar rods (perhaps 4-6 ft in length depending on current velocity and composition of bottom sediments). A

500 ft.boom will weigh approximately 1000 - 1500 lb., the anchoring rods will weigh another 200 lbs.

B.2 Oil Processing Capacity

B.2.1 through B.2.3 Concepts I through III

The oil processing capacity of devices I through III is primarily dependent on the amount of oil that can be ingested (recovered) by the device, and the rate the which the oil can actually be burned which depends on the incineration scheme (unassisted open burning as in Concepts I and III, IV and V; enhanced airflow burning as in Concept IIA; or use of a flaring burner as in Concept IIB). The first consideration is important in Concepts I through III as the ideal situation is to have sufficient oil entering the device to support the full burn capacity of the device.

Oil recovery rate for Concepts I through III can be calculated using the standard formulas developed for oil containment and skimming devices. The important parameters in the calculations are:

- Encounter Rate (ER): Amount of oil available for processing as presented to the device (entering the oil concentration boom).
- Oil Recovery Rate (ORR): The rate at which pure oil is being recovered. For the purpose of the Oil Burning Barge Concepts (I through III), the ORR is the rate at which burnable oil is being delivered to the burning area of the barge.
- Throughput Efficiency (TE): The ratio of oil recovered to oil encountered.
- Relative Speed (RS): The resultant of the vector addition of the barge tow speed and the ocean current. For example, if the barge is towed in a southerly direction at 1 knot, and the ocean current is heading in a southerly direction at 1 knot, the Relative Speed is equal to zero.

For Concepts I through III, it is assumed that oil will be concentrated and funneled into the burn area by using a standard oil containment boom, deployed in the standard U-configuration. In this configuration, the width of the boom opening is generally 30% of the boom length (0.3 X L). For Concepts I and II, a boom length of 1000 ft. is assumed, for Concept III, 500 ft. is more reasonable. This give boom opening widths (W) of 300 ft. and 150 ft. respectively.

The most variable parameter determining the volume of oil entering the burning device is the thickness of the oil slick. Near the source of a large spill, a slick thickness of 10 mm or more may be encountered but this will rapidly decrease as the oil spreads to thicknesses ranging between 0.1 mm (seen as a dark brown or black slick from an aircraft) to 0.001 mm (a light silvery sheen as observed on the surface). Slicks easily visible from the air range between 1.0 mm to 0.1 mm according to the Exxon Oil Spill Response Field Manual (Exxon, 1992). Given the envisioned use of Concepts I to III (burning larger, continuous source spills), and the need for aerial surveillance in positioning the barge, it is assumed that the slick thicknesses encountered will fall in this range (0.1 to 1.0 mm).

Using these input parameters for gap width, a slick thickness of 0.1 mm as a typical value, typical device relative speeds (0.5 to 1.5 knots), and throughput efficiencies for the boom/burning device combination of 0.80 and 0.60, typical overall recovery rates can be calculated using the formula:

Overall Recovery Rate (ORR) = relative speed (RS) (ft/s) x gap width of (A) (ft) x Oil Layer Thickness (T) (ft) x 15387.7 x TE = bbls/day of flow into the oil burning barge device.

ORR bbls/day = RS x A x T x 15387.7 x TE

These values of Overall Recovery Rate (ORR) are provided for Concepts I and II in Table B-1:

Table B-1 Values of Overall Recovery Rate (ORR) for Concepts I and II

Oil Thickness	Gap Width	Relative Speed	ORR at TE 0.80	ORR at TE0.60
0.1 mm	300 ft.	0.5 knots	1021 BPD	766 BPD
0.1 mm	300 ft.	1.0 knots	2042 BPD	1532 BPD
0.1 mm	300 ft.	1.5 knots	3064 BPD	2298 BPD
1.0 mm	300 ft.	0.5 knots	10,213 BPD	7660 BPD
1.0 mm	300 ft.	1.0 knots	20,426 BPD	15,311 BPD
1.0 mm	300 ft.	1.5 knots	30,622 BPD	22, 980 BPD

The values of Overall Recovery Rate (ORR) for Concept III are provided in Table B-2. As the HIB skimmer operates more efficiently at higher relative speeds, calculations of ORR at relative speeds of up to 3.0 knots are provided.

Table B-2 Values of Overall Recovery Rate (ORR) for Concept III

Oil Thickness	Gap Width	Relative Speed	ORR at TE 0.80	ORR at TE 0.60

0.1 mm	150 ft.	1.0 knots	1021 BPD	766 BPD
0.1 mm	150 ft.	2.0 knots	2042 BPD	1532 BPD
0.1 mm	150 ft.	3.0 knots	3064 BPD	2298 BPD
1.0 mm	150 ft.	1.0 knots	10,213 BPD	7660 BPD
1.0 mm	150 ft.	2.0 knots	20, 426 BPD	15, 320 BPD
1.0 mm	150 ft.	3.0 knots	30,640 BPD	22,980 BPD

Tests of the HIB skimmer at OHMSETT produced ORR values of approximately 150 gal/min or 5,143 BPD for a relative speed of 3.0 knots (Devitis et. al., 1996). This involved tests of a much smaller unit than the 100 ft version envisioned. Although the values in Table B-2 may overestimate the ORR for the actual HIB device, ORR values on the order of 5,000 to 10,000 BPD appear realistic.

It is clear from Tables B-1 and B-2 that for the range of parameters investigated, the Overall Recovery Rate (amount of oil entering the burn area of the device) should not be a limiting factor, and that Recovery Rates of 5,000 - 10,000 BPD are attainable for Concepts I-III. This assumes that continuous slicks of 0.1 - 1.0 mm are available for capture. This may be optimistic given the fact that slicks from oil spills at sea are discontinuous, and often only the thicker portions have thicknesses of 0.1 - 1.0 mm. Accordingly the ORR values in Tables B-1 and B-2 represent best-case Encounter Rates and Oil Recovery Rates.

The second consideration, burn rate of the oil in the burn compartment or area, is difficult to estimate as is it depends on complex factors, such as the amount of air available to support the combustion process and the distribution of air throughout the burn area, (which even for open burning is less than the stoichiometric volume required), and back radiation to the oil slick in the device which may improve oil volatilization and improve burn efficiency. For Concepts I, III, IV and V, it can be assumed that the burn rate is roughly the same as estimated for standard fire resistant boom applications.

For Concept I it can be assumed that the open area burn rate of 2.94 BPD/ft^2 (for crude oil) generally applies. *For a burn area of 25 ft X 150 ft, this gives a crude oil processing capacity of 11,025 BPD*

In Concept IIA, the objective of the barge modification is to enhance airflow to maximize burn rate. The ideal air flow for Concept IIA can be calculated as follows:

Target Burn Rate: 10,000 bbls per day.

Stoichiometric Burning of Crude Oil requires ~1360 ft^3 per gallon
10,000 bbls/day = 291.6 gal/min

291.6 gal/min x 1360 ft^3 air/gal crude = 396,666 ft^3 air/min required to burn 10,000 BPD

Given this required volume flow rate, and assuming an air flow duct area at the burn compartment entry point of 25 ft by 5 ft, allows calculation of the air velocity at the entry point as follows:

$$\text{Air Velocity (ft/min)} = \frac{\text{Air Volume Flow (ft}^3\text{ air/min)}}{\text{Total area of natural duct drafting (ft}^2\text{)}}$$

$$= \frac{396{,}666 \text{ ft}^3 \text{ air/min}}{125 \text{ ft}^2}$$

$$= 3173 \text{ ft/min} = 53 \text{ ft/sec (or roughly 31 knots)}$$

Although such air flows might conceivably be achieved using the scoop arrangement in Concept IIA with the barge pointed into a stiff headwind, the actual airflow under normal operating conditions is likely to be much less. It is also not clear that the air could be evenly distributed throughout the burn area to enhance the burn efficiency. Although directed air flows have enhanced burn efficiencies in onshore incinerator designs, these designs have relied on forced air blowers, and have been limited in size which allows for more complete distribution of air throughout the air compartment (See Appendix A, Section A.2.1). In general, efforts to improve combustion using passive air flow enhancement have not proved successful.

The most promising scheme proposed to date for enhanced combustion in an at-sea oil burning device is the concept developed by Franken *et al*. (1992). A prototype oil burning device using forced air injection to promote enhanced circulation (create a fire-whirl) achieved average burn rates of 860 BPD (see Appendix A, Section A.2.3.5). A scaled-up version of such a device (roughly 36 ft in diameter and 34 ft high) proposed by Glosten *et al*. (1991) for incorporation into an Arctic Incinerator Barge provided a projected capacity of 2100 BPD (see Appendix A, Section A.2.3.6).

Such an enhanced combustion chamber could be encorporated into Concept IIA (and possibly even Concept III). The burn rate for such a device is estimated according to the calculations below:

Burn Pool Diameter = 11.2 ft
Burn Pool Area = 98.5 ft^2

According to Franken *et al.*, 1992, such a device with stack and fire whirl burn chamber, with a burn area of 28.26 ft^2, provides burn rates of 95 liters/min. Using a conservative multiplier in scaling up the size of the burn chamber provides a burn rate of 638 gal/day/ft^2 as follows:

95 l/min/28.26 ft^2 = 859 bbls per day/28.26 ft^2 = 30.4 bbls/day /ft^2 = 1276 gal/day/ft^2

Assume 50% of 1276 gal/day/ft^2 …. 638 gal/day/ft^2 . For the larger chamber (98.5 ft^2), this provides a burn capacity of:

638 gal/day/ft^2 x 98.5 ft^2 = 62,843 gal/day = 1,496 BPD

The air requirements can be calculated as follows:

Burn Rate: 1,500 bbls per day.

Stoichiometric Burning of Crude Oil requires 1360 ft^3 per gallon

1,500 bbls/day = 43.7 gal/min
43.7 gal/min x 1360 ft^3 air/gal crude = $\underline{5{,}950\ ft^3\ air/min}$

Large blowers would be required to supply this volume of air (as proposed in the Shell Western BP design for the Arctic Incinerator Barge).

In summary, it appears entirely feasible that the enhanced air flow, fire-whirl burn chamber concept could be incorporated into an oil burning barge device (similar to that proposed by Glosten & Associates, 1991), with each combustion unit providing ~ 1500 BPD burn capacity. Two such units incorporated into Concepts IIA would provide a processing capacity of 3,000 BPD. An oceangoing barge could accommodate 3-4 such devices, providing a significant processing capacity with reduced emissions. However, such a device would require extensive re-engineering of the barge and installation of support machinery, and not provide any more overall burn capacity than Concept I. *Accordingly, a processing capacity of 3,000 is assumed as a realistic estimate for Concept IIA.*

For Concept IIB, the burn capacity depends on the capacity of the flaring burner itself. Modern flaring burner designs provide burn capacities of up to 15,000 BPD. Using an EXPRO Ltd. SuperGreen Burner (as described in Appendix A, Section A.2.2.4), with a two burner head configuration, provides a design burn rate of up to 10,000 BPD. *Assuming that the oil recovered by the barge can be concentrated and pumped to the flaring burner at this rate (10,000 BPD or ~ 300 gal/min), provides an overall processing capacity of 10,000 BPD.*

For Concept III the ORR for the 100 ft and 180 ft version of the HIB incineration barge is approximately 10,000 BPD at a relative speed of 1 knot. The burn capacities, assuming the open area burn rate calculations apply are 4721 BPD for the 100 ft version (burn area of 1606 ft^2), and 11,907 BPD for the 180 ft version (burn area of 4050 ft^2). *Although the 180 ft version provides a higher burn capacity, it is more likely that a modular, transportable unit would be 100 ft in length or less. Hence a oil processing capacity of 4000-5000 BPD is expected.*

B.2.4 through B.2.5 Concepts IV and V

Concepts IV and V are essentially fire-resistant barriers, such that the oil processing capacity can be estimated using procedures developed for determining burn rates for standard fire resistant booms as prescribed in the Exxon Oil Spill Response Field Manual (Exxon, 1992). *Assuming an average boom length of 100 - 150 ft of bubble barrier for Concept IV, deployed in a U-configuration, provides a burn area of roughly 200 - 500* ft^2. This burn area provides a burn capacity of roughly ~ 600 - 1,500 BPD for the bubble barrier. *For Concept V, a boom length of 250 - 500 ft. is easily deployed, such that the boom area is 1100 - 1500* ft^2*, providing a burn capacity of 3200 - 4,400 BPD.* This assumes, of course, that oil can be captured/diverted into the barrier to maintain the necessary oil thickness and support a continuous burn.

B.3 Stability

B.3.1 and B.3.2 Concepts I and II

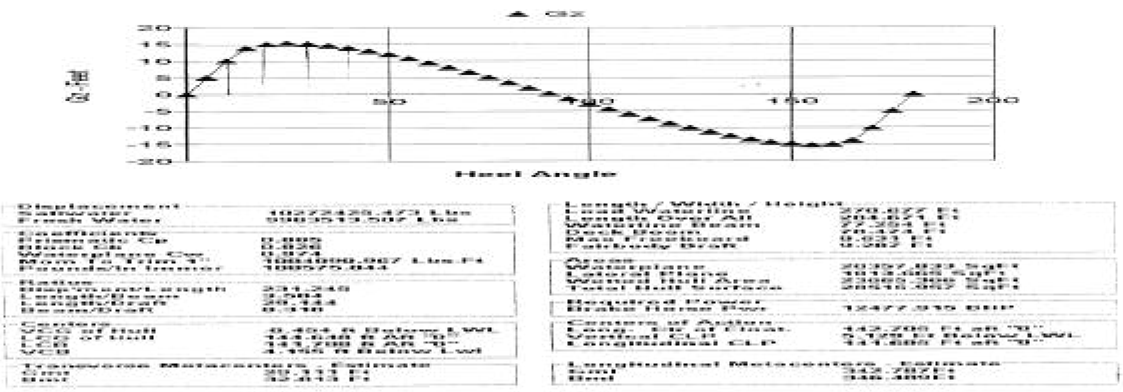
The following stability discussion applies to Concepts I and II, and to Concept III to the extent that the HIB hull form resembles a barge. The stability calculations discussed here apply to Concepts I and II.

The hydrodynamic stability of a hull form is its capability to return to an upright position when inclined to an angle off the vertical (as a ship rolling in heavy seas). Overall stability of a vessel is represented by a plot of righting arms, GZ, versus angle of inclination for several displacements, called static stability curves. The value "GMt" is the initial slope of the static stability curve and is used as a first order estimate of a vessel's stability (positive GMt value indicates stability, negative GMt value indicates instability). The range of stability is the range over which the ship has a positive righting arm (e.g., from 0 degrees to 65 degrees). Free surface effect and free communication effect are corrections to the static stability curves that result in reducing the maximum righting arm and the range of stability. (Free surface and free communication effects will be encountered in opening up the center tank of the barges in Concept I and II to allow oil to flow in and create the burn area.)

The formulas and procedures for calculating and plotting stability are not extremely complex but can be time consuming. Fortunately, there are a number of software packages available that will perform basic stability calculations and plot righting arms versus angle of heel for various displacements of a given hull form. Commercially available packages include: Ships Hull Characteristics Program (SHCP), General Hydrostatics (GHS), and PROLINES.

PROLINES is a software package available from Vacanti Yacht Design. PROLINES performs various hydrostatic calculations such as displacements (e.g., fresh water and salt water), various coefficients (e.g., prismatic, block, waterplane), ratios (e.g., displacement to length, length to beam, length to draft), centers (e.g., VCG, LCG, LCB, VCB, LCF), metacenters (e.g., GMT, BMT, GML, BML), principal dimensions (e.g., LOA, Load Waterline, Waterline Beam, Max Freeboard, Fairbody Draft), areas (e.g., waterplane, lateral plane, wetted hull, total hull surface), required power, wave and friction drag, etc. There are two versions of the software: Basic and Professional.

For the purposes of this study, the Basic version (PROLINES 6.29) was used to perform the intact stability calculations using a hull form representative of the 2760 Oceangoing barge design. The Table of Offsets for this hull form were obtained from the Coast Guard Marine Safety Center. The results from these calculations are shown in Figure B-3 (which includes a plot of the righting moment Gz vs. Heel Angle along with the tabulated hull characteristics and stability values). The large area under the curve from 0 to 90 degrees of heel angle is indicative of a stable hull form, as is the high value of GMt (29.1 ft.).



However the primary yardstick for determining the safety of a ship is neither GMt nor the range of stability but the maximum righting arm and the angle at which this maximum occurs. In this case the maximum righting arm, GZ, is 15 feet at 25 degrees of heel.

Applicable stability criteria are specified by the Coast Guard, in NVIC 4-92 dated 2 April 1992 for new tank vessel, which states:

> The righting energy should not be less than 10.3 feet-degrees up to 30 degrees of heel and not less than 16.9 feet-degrees up to 40 degrees of heel, or the down flooding angle, if that angle is less than 40 degrees. Additionally, the righting energy between 30 and 40 degrees (or between 30 degrees and the downflooding angle, if that angle is less than 40 degrees) should not be less than 5.6 feet-degrees ...... The righting arm at an angle of heel equal to or greater than 30 degrees should be at least 0.66 feet....... The maximum righting arm should occur at an angle of heel preferably exceeding 30 degrees, but not less than 25 degrees......   The initial metacentric height, GMt, should not be less than 0.49 feet.

The barge hull form provided by the USCG Marine Safety Center, as modified to permit burning in the center tank area, was analyzed at its normal expected operating displacement of 4585 tons. This displacement is achieved by pressing up (completely filling) four of the ten buoyancy (wing tanks) with salt water and flooding all five centerline tanks to the waterline (9.3'). At this displacement, the barge hull form analyzed has an actual righting energy of 315 ft-degrees up to 30 degrees of heel and 455 ft-degrees up to 40 degrees of heel. The actual righting energy between 30 degrees and 40 degrees is 140 ft-degrees. The actual righting arm at an angle of heel equal to or greater than 30 degrees is 14 feet. The actual maximum righting arm occurs at 25 degrees. The actual initial metacentric height is 29.1 feet. *In summary, the stability of the barge hull form analyzed for Concepts I and II meets or exceeds all intact stability criteria by a substantial margin.*

Free Surface Correction: Another consideration in determining the stability of the oceangoing barge hull form is the free surface correction. Since the centerline tanks will be opened up to form the burn area, this “centerline tank” will be flooded to the waterline. This creates a substantial free surface which has the effect of reducing the metacentic height (GMt - the measure of initial stability), which is equivalent to a virtual rise in the center of gravity since the actual location of the metacenter does not change. The calculation for the free surface correction which produces a new “effective” GM is as follows:

FSC = moment of inertia of the free surface area/volume of displacement

$$FSC = (b^3/12)/(4585)\ (35) = (25)^3(250)/12 = 2.0 \text{ ft}$$

$$GMeff = GM - FSC = 29.1 \text{ ft} - 2.0 \text{ ft} = 27.1 \text{ ft}$$

In general, this small change in the metacentric height (2.0 ft.) is not considered problematic because the initial GMt (uncorrected for free surface) is so large. *Therefore, the free surface created in the burn area is not considered a problem in the initial or overall stability of the barge*.

B.3.3 Concept III

Stability and seakeeping information for the HIB hull form was obtained from Webster Barnes, Inc. The vessels have high initial GMt, by virtue of their configuration (two wing tanks separated by a considerable distance with the center area flooded - essentially approximating a catamaran hull form). They are not subject to significant overturning forces at large angles. Compartmentation of the side tanks makes reasonable damage stability relatively easy to achieve.

To verify the stability of Concept III, the PROLINES software package was also used to perform the basic intact stability calculations for the 180 ft. version of the HIB hull form as proposed by Webster Barnes. The results of these calculations are shown in Figure B-4. The actual righting energy is 138.5 ft-degrees up to 30 degrees of heel, and 200.5 ft-degrees up to 40 degrees of heel. The actual righting arm energy between 30 and 40 degrees is 62 ft-degrees.

The USCG recommended stability criteria for a standard barge hull form are described in Section B.2.2. and compare to the stability values for the 180 ft HIB hull form as follows:

1) The righting arm at an angle of heel equal to or greater than 30 degrees should be at least 0.66

ft. The calculated value for the 180 ft HIB hull form is 6.5 ft.

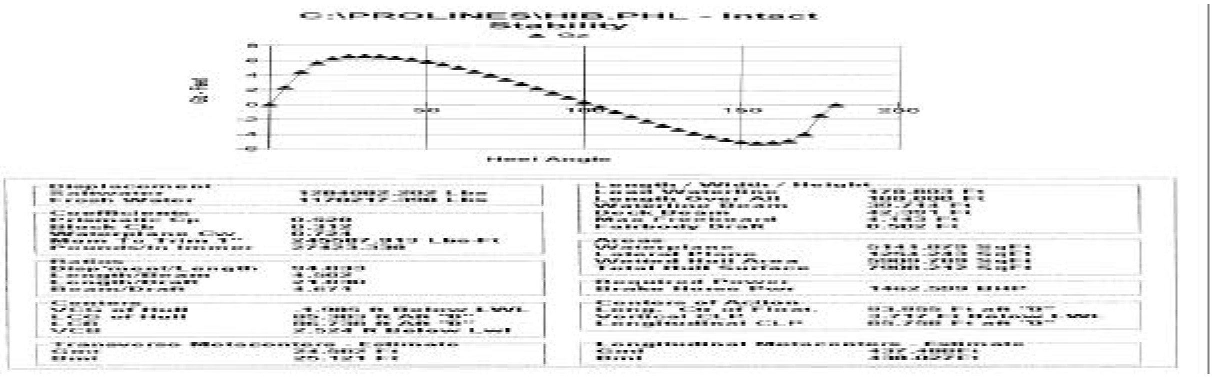
2) The maximum righting arm should occur at an angle of heel preferably exceeding 30 degrees, but certainly not less than 25 degrees. For the 180 ft HIB hull the maximum righting arm occurs at 30 degrees.

3) The initial metacentric height (GMt) should be no less than 0.49 ft. For the 180' HIB hull, the value of GMt is 24.6 ft.

In summary, the 180' HIB hull form appears to be highly stable. As the 100 ft HIB hull form is geometrically similar to the 180 ft version, it is undoubtedly stable as well.

B.3.4 - B.3.5 Concepts IV and V

Stability is not an issue for these concepts.



B.4 Seakeeping

B.4.1 and B.4.2 Concepts I and II

Six degrees of freedom: roll, pitch, heave, yaw, surge and sway can be measured in model tests and full scale tests. The modified barge (Concepts I and II) would require model tests or full scale tests to fully characterize ship motions in a seaway. Both of these tests are considered outside the scope of this study. At towing speeds anticipated and considering environmental conditions likely to be encountered in the various scenarios described, seakeeping characteristics should not be a limiting factor. *The barge hull form provided by the Coast Guard Marine Safety Center represents an existing barge that has been approved by the U.S. Coast Guard. Therefore it is assumed to have acceptable seakeeping characteristics. Oceangoing barges of this type often operate in sea states above those that would be encountered during oil recovery and burning operations (0-3 feet).*

B.4.3 Concept III

The HIB skimmer motion is inherently very well-damped by the entrained mass of the separation area. In addition, its configuration results in relatively low excitation from the sea surface. *These two factors—low excitation and highly damped response—result in a vessel that remains highly stable even in severe sea states*. Inevitably, bow slamming is a potential limitation on advanced speed when encountering high sea states. This condition is common to any similarly- shaped barge.

B.4.4 Concept IV

Seaworthiness for this concept translates to the water depths, current and wind speeds under which it will be deployed. *The literature indicates that system should work well in water depths of 2-6 feet, current speeds up to 1.0 knots, and wind speeds up to 10 knots*. This covers many river and estuarine scenarios.

B.4.5 Concept V

The fence boom concept can be deployed in water up to 3 feet, and currents of 0 - 1.0 knots. Higher currents can be dealt with by angling the boom with respect to current flow, until oil is guided into quiescent water near shore.

B.5 Materials/Fire Resistance

B.5.1 through B.5.3 Concepts I, II and III

Depending on the intensity of the fire and the duration of the burn, it may be necessary to construct or modify the barge hulls in Concepts I, IIA and III to make them durable enough to function during extended burn operations without risk of structural failure. However, as current oceangoing barges are constructed of steel, the basic hull should be suitable for the purpose. It has been clearly shown in past barge accidents (explosions and fires) that the barge hulls remain intact even after spectacular fires which consume the cargo (e.g., the Barge Ocean 255 involved in the 1993 Tampa Bay Spill).

Steel as opposed to aluminum is required in the burn area due to its superior ability to withstand the heat generated by the burning oil. Other materials may be suitable (e.g., titanium); however, ease of construction and costs to procure and fabricate dictate use of steel. Research of background materials indicates that the following heat release rates and maximum temperatures may be experienced during the burn:

- Heat release rates for in-situ oil fires on water range from 1.76 MW/m^2 for ANS crude to 2.34 MW/m^2 for diesel fuel. (McCourt *et al*., 1997). This can result in net heat flux to a fire-resistant boom or barge hull of 150-200 MW/m^2.

- Maximum temperatures experienced in containing an oil fire (measured at the top of a fire-resistant boom) can reach 1000 °C and above (Buist et. al., 1994a).

- Flame heights will be generally twice the flame diameter for fire diameters on the order of 10 meters and less (Buist *et al.*, 1994a).

Bare steel will withstand the heat generated by burning of oil up to a certain point. Complex calculations are required to determine the exact length of time the steel will withstand the fire before serious deterioration is experienced. A36 structural steel is the most commonly encountered steel used in ship construction. Tests have demonstrated that A36 steel will fail in the range of 1000 deg F (538 deg C) to 1100 deg F (593 deg C) which is well below the maximum 1660 deg F expected during in-situ burning of oil. Certain alloys of iron and chromium are highly resistant to corrosion and oxidation at high temperatures and maintain considerable strength at these temperatures. Certain austenitic stainless steels for example are capable of withstanding temperatures up to 2000 deg F. These heat resisting austenitic stainless steels contain relatively high percentages of both chromium (up to 26%) and nickel (up to 22%). AISI 310 stainless steel is considered the most economical heat resisting austenitic stainless steel and will easily withstand the temperatures typically encountered during in-situ burning of oil indefinitely without the need for insulation. The yield strength of 310 stainless steel is 40,000 psi compared to 36,000 psi for A36 steel. 310 stainless steel is easily weldable, thus this steel is an excellent material for barge construction. Due to relatively higher costs however ($2.20/lb), 310 stainless steel should be used only in the area exposed to high temperatures; the rest of the barge may be constructed of A36 structural steel ($0.40 - 0.60/lb).

For Concept I the assumption is that as little modification should be made to the barge hull as possible. *It will be necessary to line the burn compartment with stainless steel or utilize a simple water cooling scheme (See Section B.6) to keep the hull from failing. Even with a stainless steel liner, some form of cooling will be necessary to keep the steel from warping and degrading the integrity of the hull. In addition to protecting the interior bulkhead in the burn compartment, the deck will either have to be cooled or made of stainless steel to prevent warping from the heat radiated from the flame.* Within one fire diameter length of the center of the flame, surfaces will experience flame radiative heat fluxes of greater than 10 MW/m^2. (This is sufficient to char and ignite wood.)

For Concept IIA, *the barge hull can be constructed of mild steel as the hull will be protected by restricting the burning process to the combustion chambers integrated into the hull (such as in the Shell Western BP Arctic Incinerator design).* The combustion chamber will have to be constructed of stainless steel and air and water cooled as described by Glosten (1992).

For Concept IIB (the Flaring Burner Barge), the fire resistance of materials is not a major issue as combustion does not occur inside the barge. *For Concept IIB, the barge hull is protected from flame radiation by use of a water spray behind the flaring burner.* This technique is routinely employed in offshore platform applications.

For Concept III, there will be a trade-off between the weight of the hull and its heat resistance. The current HIB hull is made of aluminum which is lighter and more transportable but not suitable for burning. *The hull used in burning should be constructed of stainless steel, or at least the center portion that comes in contact with the flame and the deck which will be subject to flame radiation. With appropriate water cooling and/or insulation, it may be possible to construct the flotation hull (wing tanks) of aluminum to conserve weight.*

B.5.4 Concept IV

Fire resistance is not an issue as the hose is submerged in the burn area.

B.5.5 Concept V

Fire resistance can be augmented by increasing the thickness of corrugated metal or simply replacing sections in the burn area at appropriate intervals. Fence boom sections should be relatively inexpensive. Boom layers could be doubled-up in the burn area with the inner layer considered sacrificial.

B.6 Insulation/Cooling

B.6.1 through B.6.3 Concepts I, II and III

There are several types of insulating materials and cooling techniques that appear to be feasible for use in Concepts I, II and III:

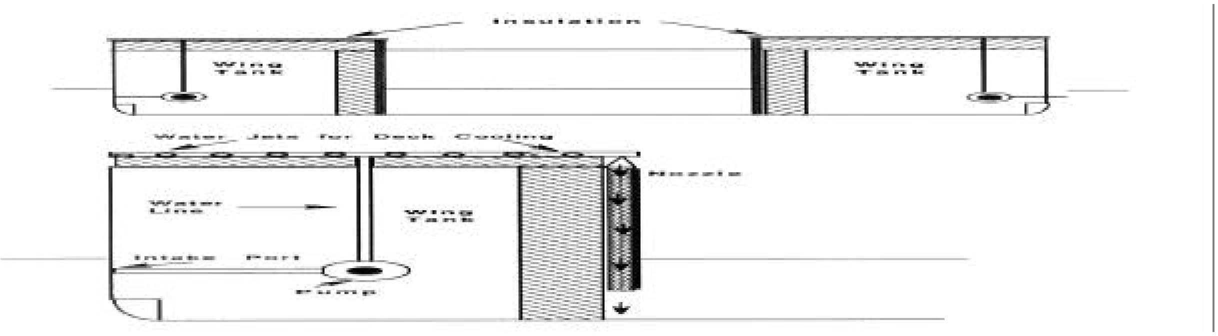
Water Spray: Water can be pumped through a piping network to a series of nozzles that are designed to provide a "sheet" of water over the surface to be cooled. This will absorb and carry away any heat from the fire thus protecting the steel substrate. A modification of this approach is to pump water through a porous medium contained in a double-wall that lines the burn area. Schematics of these approaches are shown in Figures B-5 and B-6.

Ceramic Tile: Ceramic tile installed with a 4" air gap will provide thermal protection. This will require installation of a double-wall in the burn area. The advantage of this option is that pumps are not required as with the water-spray option. Additional calculations are required to determine minimum thickness of tile. It is also likely that ceramic tile insulation will be costly both in the cost of the tiles and the cost of installation.

Starlite: The science and technology section of the August 16, 1993 issue of Business Week (business Week, 1993) describes a plastic which has been demonstrated to endure spot temperatures of 10,000 deg C. Photographs taken during tests have shown that a thin layer of ionized gas forms on the surface of the material that insulates the plastic. Tests have also demonstrated that a warhead can be heated to 900 deg C in nine seconds but a paper-thin layer of Starlite will prevent the temperature from rising above 40 deg C. Therefore cladding the burn area of a barge being used for in-situ burning of oil with Starlite should adequately insulate the steel or aluminum from the heat of the fire. Since only a paper-thin sheet of Starlite is required, there should be no substantial addition of weight to the barge. Although this technology could have important applications in the design of fire-resistant boom and oil incineration devices, Starlite is still in the R&D stage. Engineering implementation, fabrication and cost considerations would have to be explored.

TempCoat: is a premixed composite material consisting of 80% microscopic, air-filled ceramic and silicon beads. These precisely manufactured beads are held in suspension by a high grade latex paint base with acrylic binders and uniquely formulated resins yielding an extremely light-weight, pliable product which expands and contracts with the surface to which it is applied. The unique and superior insulating capacity of TempCoat is the result of air within the hollow glass beads serving as a thermal barrier much like double-paned thermal glass windows. TempCoat is applied much like conventional paint. One coat is approximately 15 mils thick. Testing may be needed to determine the appropriate thickness to adequately protect the steel in the burn area of a barge. This is clearly the simplest option in that a double-wall is not required. However the cost of coating a large area may be a constraint.

In summary, it appears that there are a number of viable options to improve the durability of the hull forms used in Concepts I, IIA and III. The most straightforward is a simple water cooling scheme for the walls of the burn area and the exposed deck. Further design calculations and testing will be necessary to implement these options. For Concept IIB, the cooling mechanism is provided by the water spray behind the flaring burner itself.



B.6.4 - B.5.5 Concepts IV and V

Insulation and cooling are not an issue for these concepts.

B.7 Ignition Mechanism

Laboratory studies have been done to determine the conditions under which oil could be ignited on water and to evaluate various techniques for achieving ignition. It was found that a fresh layer of oil had to be at least 1 mm thick; a thickness of about 5 mm was required if the oil was weathered. Other requirements included a high flame temperature and a large flame projected close to the oil without disturbing it.

B.7.1 through B.7.3 Concepts I, II and III

Much research and testing have been devoted to the development of igniters which can be used for in-situ burning of oil (e.g., in a fire-resistant boom or oil pools in ice) as described in detail in Appendix A, Section A.5.1. These techniques and devices assume a one-time ignition of the oil which is then allowed to burn freely until it is consumed. These techniques are directly applicable to the ignition of the oil in Concepts IV and V. For Concepts I, II and III, it will be desirable to have the ability to extinguish and re-ignite the flame at intervals as the supply of oil to the device may be interrupted, or operations may have to be suspended to reposition the device.

Three possible ignition systems are envisioned for Concepts I, IIA and III. For Concept IIB, the igniter is included in the flaring burner design.

<u>Propane Ignition System</u> - A propane jet mounted on the inner wall of the hull (in the burn area) projects a flame at the oil surface when ignition is desired. Several jets would be mounted most likely near the rear of the burn area where the oil will be the thickest. Figure B-7 shows a schematic of the system. The system is controlled remotely (via telemetry) from the towing/tending vessel. The propane is ignited using an electrical filament. The advantage to this system is its simplicity and reliability - propane is widely used for other ignition applications such as flaring burners. The primary drawback is the use of propane which is a hazardous material and generally discouraged for shipboard applications (being heavier than air, propane can collect in hull spaces and pose an explosion hazard). The immediate proximity of the propane tanks to a large flame and heat source will require extensive precautions.

<u>Diesel Ignition System</u> - This approach is the same as the propane system but uses ordinary diesel oil as the fuel, similar to a burner in a furnace used for home heating. Diesel oil is less hazardous than propane, and a small amount will be sufficient for ignition purposes. *As diesel oil is routinely carried on barges, no additional inspection and certification requirements are anticipated. Of all the options, this appears to be the most viable for Concepts I, IIA and III.*

Napalm (Helitorch) System - Such a system would be a shipboard adaptation of the Helitorch used to ignite oil during in-situ burn operations using fire-resistant boom (see Appendix A, Figure A-9). The device, suspended from a helicopter (hence Helitorch), dispenses gelled gasoline (napalm) into the oil and serves as a highly effective ignition device in this application. It is possible that this system could be adapted for shipboard use. The major design problems are distributing the napalm over the oil (it is difficult to suspend the distribution system above the flame area without having it be subsequently damaged by the flame) and the general complexity of the system. Again having a highly volatile fuel in close proximity to heat and flame would require considerable engineering to ensure safety. Figure B-8 shows a schematic of a simple Helitorch-like system mounted on the Concept I barge.

B.7.4 and B.7.5 Concepts IV and V

As stated above, several techniques and devices have been developed for igniting oil inside a barrier or in a pool. These should also be effective for Concepts IV (bubble barrier) and V (metal fence boom). Typical methods used for oil ignition include:

Simple Floating Igniters - These consist of a piece of sorbent material or container with an accelerant which is ignited and allowed to float back into the oil slick. For instance, a floating bag of gelled gasoline was used to ignite the successful burn during the EXXON VALDEZ spill. *Because of the relatively small size of the burn operation involving the use of Concepts IV and V, the use of simple, hand-deployed floating igniters is the simplest ignition method.*

Helitorch Igniters with gelled gasoline - A helicopter slung device that distributes packets of burning gelled fuel. Gelled crude oil was found to be a better igniter than gelled gasoline. The "Helitorch" aerial ignition system should be able to ignite relatively fresh (up to 12 hours at sea) crude oil and emulsions with water content in excess of 25% but less than 50%.

B.8 Emissions Control

In-situ burning of spilled oil has met with opposition in part because of the smoke produced. In those open ocean or remote areas where burning of oil in situ is feasible, reducing the smoke production may not be necessary. However, in nearshore and harbor areas, where many spills occur, smoke reduction is highly desirable(assuming that is-situ burning would be approved). Studies have investigated the ability of various additives and techniques to reduce the amount of smoke emitted.

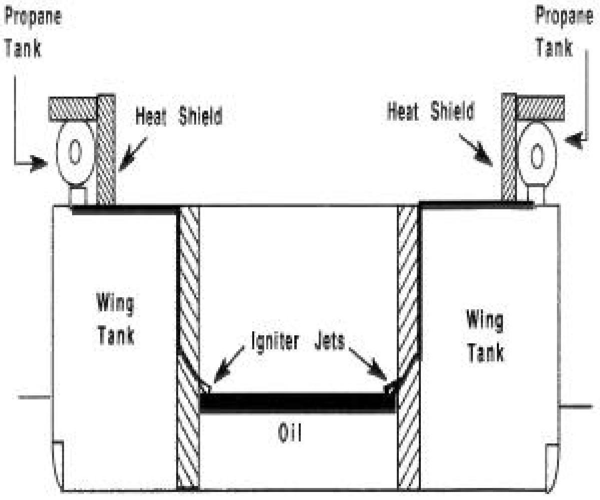
Ferrocene - The primary smoke suppression additive investigated for oil spill burning is ferrocene as described in Appendix A, Section A.4.3. Ferrocene is a non-toxic, organometallic compound that is soluble in hydrocarbon fuels but not soluble in water. Iron oxide is produced by burning of the ferrocene/fuel mixture. Because iron oxide fouls combustion chambers, ferrocene has had limited use in enclosed incineration devices. In direct burning of an oil spill, however, iron oxides are released into the atmosphere; they are non-toxic and are emitted in smaller quantities than soot. Open pool burning using Concept I and III could thereby utilize this technology. The most promising additive, RMS-9757, is a liquid that can be sprayed onto the oil spill (Mitchell and Moir, 1992). RMS-9757 was most effective in reducing soot when used at about 2 % by weight (2wt%) of ferrocene equivalent; however, a treatment rate of about 0.5 wt% was found to be most cost effective. The drawback is the cost of the material ~ $400/lb for pure ferrocene.

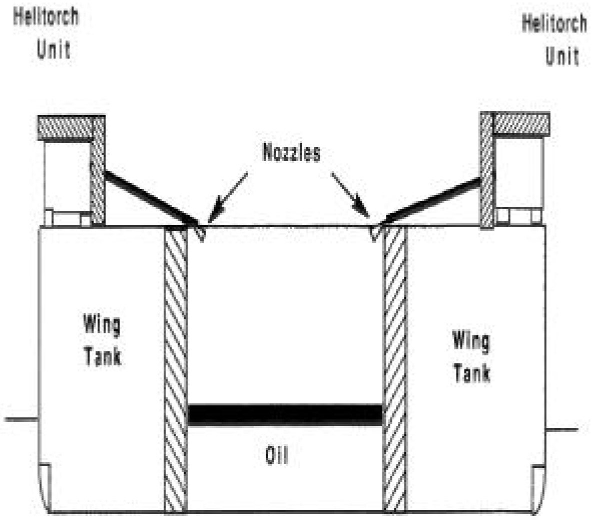
Enhanced Airflow - The process of in-situ burning using the standard fire-resistant boom approach is inherently inefficient. Although there is plenty of air available from the atmosphere (400% of the stoichiometric requirement), not enough air can be supplied to the interior of the burn pool to meet the stoichiometric requirements. Accordingly, the burn is inefficient, and black smoke, unburned oil and soot particles are advected upward, producing a highly visible emissions plume. Such a plume is anticipated with the concepts under consideration (specifically I, III, IV and V), unless an emissions reduction scheme is incorporated in the design (as in Concepts IIA and IIB).

Two approaches to supplying additional air have been investigated which are applicable to Concepts I and III. The first involves increasing the volume of airflow into the burn area using blowers, and inducing a circular flow within the burn area, which generally leads to reduced emissions (and particularly visible emissions). This approach was first investigated in the development of incinerators for the burning of oil and oiled debris on land. These efforts are described in detail in Appendix A, Section A.2.1. Although effective in smaller combustion chambers, it is not clear that this approach can be scaled-up for the devices in question.

A more recent development effort focused on the use of circular vanes (to stimulate circular airflow), in conjunction with the injection of air at the base of the flame, as described in Appendix A, Section A.1.2.5. The approach developed by Franken was subsequently incorporated into the conceptual design for an Arctic Oil Incinerator described in Appendix A, Section A.2.3.6.

Flaring Burners - One approach to reducing emissions and enhancing combustion is not to burn the oil in the burn pool area itself, but to collect it using a sump device (weir skimmer) and pump it to a flaring device on deck. The development of such flaring devices is described in detail in Appendix A, Section A.2.2. This technology has made significant progress since the earlier efforts of the 1970's and 1980's. Most recently Expro, Ltd., in the U.K. has developed flaring devices which can burn 5,000 to 15,000 BPD with minimal visible emissions.


Propane
Tank
Heat Shield
Propane
Tank
Heat Shield
Wing
Tank
Igniter Jets
Wing
Tank
Oil


Helitorch
Unit
Helitorch
Unit
Nozzles
Wing
Tank
Wing
Tank
Oil

B.8.1 and B.8.2 Concepts I and II

These two concepts offer the opportunity for employing emissions suppression and control technology as the burn area is surrounded by a stable platform which can support systems to enhance airflow and increase combustion effectiveness. *Enhanced airflow combustion units such as those proposed by Franken (1992) and refined in the Arctic Incinerator design (Glosten, 1991) can be incorporated into Concept IIA to provide for emissions reduction*. However, this will require considerable re-engineering of the barge and installing the supporting machinery. *The use of a deck-mounted flaring device, which is specifically designed to reduce emissions, forms the basis for Concept IIB.* These emissions control measures involve greater complexity and cost. A simple ferrocene application system (e.g., gravity fed from a tank and distribution system located on the deck which adds the ferrocene to the oil as it enters the burn area) is also technically feasible but will probably be cost prohibitive in view of the large quantities of oil to be treated.

B.8.3 Concept III

In theory, all of the smoke suppression techniques and devices suggested for Concept II could be applied to Concept III as well. However, as a practical matter, the desire for a modular, easily transportable device for Concept III will probably preclude machinery-assisted air injection and the use of a flaring burner. The use of a simple, gravity-feed ferrocene distribution system as the oil enters the burn area (perhaps mounted on the submersion plane itself) may be a viable, albeit costly, alternative.

B.8.4 and B.8.5 Concepts IV and V

Emissions control is not an issue with these concepts as transporting emissions control equipment (e.g., ferrocene tanks and sprayers) will be prohibited in the remote, shallow-water areas (marshes and tidal creeks) where Concepts IV and V are likely to be applied. In cases where in-situ burning has been applied in nearshore areas, the smaller size of the burns, the distance from populated areas, and the immediate benefits of removing the oil have outweighed the general concern about ISB emissions.

B.9 Fire Suppression

In general, selection of a fire-extinguishing system for the class B oil fire should take into consideration the following:

- Type of firefighting agent (e.g., CO2, AFFF, Hi-Expansion Foam, Water Mist, Halon alternative)
- Environmental considerations (ozone depletion potential, global warming potential)
- Cost of the agent (varies significantly, but quantity required varies simultaneously)
- Quantity of agent required (on-board storage requirements, logistics/replenishment considerations)
- Complexity of delivery system (fixed piping systems, hose reels, manual extinguishment)
- Manual or automatic release of the agent (automatic systems are more complex, manual release requires decision making and training).

B.9.1 through B.9.3 Concepts I, II and III

For concepts I, II and III, fire/suppression extinguishment falls into two categories. The first is controlled suppression used to regulate the intensity of the burn and resulting heat stress on the hull, or intermittent extinguishment to allow for repositioning of the device, removal of burn residue, and inspection and repair. Controlled suppression can be achieved by moving out of the oil slick (thereby removing fuel) for Concepts I, IIA and III. For Concept IIB, combustion rate is controlled by limiting the flow of oil to the flaring burner.

Extinguishment can be accomplished by the same procedures which will allow the fire to burn out over time. However, it may be necessary to provide a procedure or system which will permit immediate extinguishment of the fire in an emergency (e.g., engine failure on the tow vessel or approaching severe weather). To accomplish this, three possible approaches are envisioned.

Water Spray System - This is the simplest system and relies on cooling the burning oil below the ignition point. It requires only a water pump and a system of spray nozzles located on the periphery of the center burn area. It can be configured as an option to the water spray cooling system (Figures B-7 and B-8) using the same pump used to supply cooling water. A simple control manifold can be used to direct water to either the hull cooling system or fire-suppression system. A possible drawback is that the water spray may emulsify the oil making re-ignition more difficult.

CO2 (or Halon Alternative) System - This system would distribute CO2 into the burn area along the inner wall at the base of the flame. Extinguishment using this system will be far more rapid than with the water spray system. Implementation will require installation of the CO2 lines inside the wing tanks and a supply of compressed CO2 gas. The system can be activated by remote control from the tow vessel. Re-ignition will require venting of the CO2 from the burn area such that there will be a modest delay before re-ignition can occur. A halon alternative can also be used as the extinguishing gas, although this will be more costly.

Given the worse case that 100% of the calculated burn area of 4200 square feet is burning, calculations for the quantities of CO2 needed are as follows:

- *Minimum CO2 Concentration for Extinguishment*: In accordance with table 2-3.2.1 in NFPA 12, Standard on Carbon Dioxide Extinguishing Systems, the minimum design concentration for lube oil, kerosene, and higher paraffin hydrocarbons is 34%. The volume factor used to determine the basic quantity of CO2 required to protect an enclosure containing a material with a design concentration of 34% is found in Table 2-3.3 of NFPA 12. Since the largest volume of the barges considered in Concepts I, II, and III are as follows:

  Concepts I and II Volume: 250 ft x 25 ft x 8.6 ft = 53,750 cubic feet
  Concept III Volume: 146.5 ft x 28 ft x 4 ft = 16,408 cubic feet

  In accordance with Table 2-3.3 the volume factor and calculated minimum quantity of CO2 is:

  Concepts I and II: .046 lb CO2/cu ft and not less than 2500 lb
  Concept III: .050 lb CO2/cu ft and not less than 250 lb

  Therefore the total quantity of CO2 required is:

  Concepts I and II: .046 lb CO2/cu ft x 53,750 cu ft = 2472.5 lbs CO2 ~ 2,500 lbs CO2
  Concept III: .050 x 16,408 = 820 lbs CO2

  Note it would be prudent to have a quantity of agent equal to three times the amount needed to extinguish one fire. This would also account for leakage of CO2 during application. Therefore at least 7,500 lbs of CO2 should be provided for Concepts I and II and 2,460 lbs of CO2 should be provided for Concept III.

- *Rate of Application:* For surface fires NFPA 12 specifies that the design concentration must be achieved within 1 minute from the start of discharge. Nozzle discharge rates are to be calculated using the "rate by area" method as specified in NFPA 12. Therefore the detailed design of the distribution piping system and quantity of nozzles must provide for a 34% design concentration in 1 minute or less in the calculated volume with an appropriate safety factor to account for wind and leakage of agent.

Foam System - A third option is the use of AFFF or High-Expansion Foam to smother the flame. The foam could be injected directly into the burn area using a distribution system similar to the water spray/CO2 systems, or produced by the tow vessels and allowed to drift back into the device. Installation of a foam system on the barge will require additional engineering and expense. In addition, the foam must be allowed to dissipate before re-ignition can occur which may result in considerable delays. Production aboard the towing vessel is straightforward and should be considered as a possible emergency backup measure to a fire-suppression system installed on the barge.

Given the worse case that 100% of the calculated burn area of 4200 square feet is burning, calculations for the quantities of AFFF and water needed are as follows:

- *Foam Solution Application Rate*: In accordance with table 3.7.1.1 in NFPA 11, Standard for Low Expansion Foam, the minimum application rate for diked areas involving hydrocarbon liquids is 0.16 gpm/sq ft for foam monitors and 0.10 gpm/sq ft for fixed low -level foam discharge outlets. In either event the minimum discharge time for class I hydrocarbons is 30 minutes and 20 minutes for class II hydrocarbons. Class I hydrocarbons have flash points below 100 deg F and class II hydrocarbons have flash points between 100 deg F and 140 deg F. Therefore calculations will be based on 0.16 gpm/sq ft application rates and 30 minute discharge times to ensure adequate quantities of AFFF will be on hand.

  Rate (gpm) = 0.16 gpm/sq ft x 4200 sq ft = 672 gpm

- Foam Concentrate Rate: AFFF is available in 3% and 6% concentrations. 6% is more commonly specified for this application.

  Rate (gpm) = 0.06 (%) x 672 gpm = 40 gpm

  Note that a continuous supply of 6% AFFF concentrate must be available at a rate of 40 gpm for the required duration of discharge (30 minutes).

- Water Application Rate: The water application rate is the foam solution rate minus the foam concentrate rate.

  Rate (gpm) = 672 gpm - 40 gpm = 632 gpm

  Note the pumps on the tug or on the barge which will be used to discharge the AFFF solution must be designed to discharge a minimum of 632 gpm of water.

- Gallons of Foam Required:

  Agent = 40 gpm x 30 minutes = 1200 gallons

  Note it would be prudent to have a quantity of agent equal to three times the amount needed to extinguish one fire. Therefore at least 3,600 gallons of 6% AFFF concentrate should be stored on board the tug.

In summary, there are a range of viable options for providing a fire-suppression/extinguishment capability on board the barge/skimmer used in Concepts I-III. The simplest is to move the device out of the oil slick. For immediate, emergency extinguishment, a simple CO2 or AFFF foam injection system could be provided, particularly for Concepts I and IIA. For Concept III, a viable option is to release foam into the oil concentrating boom and burning device from the tow vessel.

B.9.4 Concept IV

Suppression/extinguishment in Concept IV is best achieved by shutting down the blower which immediately removes the oil concentration barrier and causes the oil slick to spread out such that the thickness falls below the minimum level (2 mm) to support combustion. This must be done with care as the burning oil may drift some distance from the initial burn area. Backup firefighting equipment (CO2 fire extinguishers) should be stationed on scene. The use of ATF foam should be considered as an emergency backup where the burn is conducted in proximity to secondary fire hazards.

B.9.5 Concept V

The easiest way to suppress or extinguish the burn is to divert the oil from the burn area using a conventional shallow-water boom. The use of ATF foam should be considered as an emergency backup.

B.10 Oil Residue Capture

The fate and composition of residues remaining after an in-situ burn are central to the issue of using in-situ burning for oil spill clean up. Oil residue left after in-situ burning operations has remained at the surface (e.g., at the EXXON VALDEZ and NOBE burns). Whether the oil residue sinks or floats depends on the properties of the original oil, changes in physical properties during burning, and density of the surrounding waters. Regardless of whether burn residue floats or sinks, the presence of polycyclic aromatic hydrocarbons (PAHs) in burn residues will continue to cause concern. The potential environmental threat posed by PAHs will depend on the species of compounds that persist in the residue, their biological activity, and bioavailability from the semi-solid residue. Accordingly, residues produced by burning operations should be removed from the environment and disposed of if at all possible.

B.10.1 through B.10.3 Concepts I, II and III

A mechanism should be provided for removing residue at intervals during the burn to prevent build-up to the point where combustion is hampered. *As previous research and experience indicate that burn residue will remain buoyant, this could be accomplished by installing a gate at the rear of the barge device such that residue can be periodically flushed out and collected by an auxiliary vessel.* This will require extinguishing the fire. A system for removing residue during burning could be devised, but the complexity of such a device appears prohibitive. For residues than sink, some means of capturing the oil that sinks to the bottom of the barge should be considered (e.g., a sump at the rear of the burn area).

B.10.4 Concept IV

Removal of residue with the bubble barrier is complicated in that shutting down the barrier to extinguish the fire will also allow the residue to disperse. *The best strategy is to allow the fire to burn out with the barrier activated, and then remove residue with vacuum hose or dip nets. A secondary, conventional, shallow-water boom can be deployed downstream of the burn area to catch residue both during and after fire is extinguished.*

B.10.5 Concept V

Residue is best removed once the fire is extinguished and residue allowed to cool. Residue can be removed with dip nets, sorbents, or vacuum hoses.

B.11 Availability and Time/Cost to Construct

There are two basic approaches to implementing the concepts/devices that are described and discussed in this report. The first is to assemble a system using existing components, making modifications to the basic components and fabricating additional components as necessary (as in Concepts I, II and V). The second approach is to design and build the necessary system and supporting components from scratch (as in Concepts III and IV).

The following discussion summarizes the availability of existing components, estimates the time and cost to modify the existing systems, and provides estimates of the time and expense required to build systems from scratch. Inquiries to shipbuilding companies indicate a general reluctance to provide estimates for hull alterations and systems that are described in only conceptual terms. Accordingly, estimates for shipyard work and ancillary systems are largely based on the experience and knowledge of the project team. Any effort to proceed with further development and testing of a concept would be preceded by a more comprehensive engineering design and analysis, to allow for more accurate cost estimates of materials and fabrication costs.

B.11.1 and B.11.2 Concepts I and II

Concepts I and II both start with the acquisition of a standard oceangoing barge hull. Fortunately, there are a number of these available at any one time as demonstrated by the market survey presented in Tables B-3 and B-4 (which was conducted in June 1996). The cost of the barge hulls ranges from approximately \$300,000 to \$2,000,000 depending on the size, age and condition of the barge. *For this analysis, a base price for the barge hull is estimated at \$500,000.* The primary unknown is the cost to modify the barge and add ancillary systems. Gross estimates of these costs for Concepts I and II are provided in Tables B-5 and B-6 respectively. *Cost estimate for modification of an existing barge for Concept I is approximately $125,000. Total cost for Concept I is thus roughly $625,000.* This assumes that only water cooling is employed without using stainless steel or insulating materials (e.g. ceramic tile) to fortify the burn compartment and deck. Such additional measures could easily increase the cost above $1M.

The cost estimate for modification of an existing barge hull (base cost $500,000) for Concept IIA is approximately $200,000. This does not include the cost of fabricating the combustion units described in Section B.2. *Each combustion unit is expected to cost at least $250,000 - $500,000 including supporting machinery and installation. At least two combustion units are envisioned for Concept IIA. Hence, a conservative estimate of the total costs to produce the device embodied in Concept IIA ranges from $1,200,000 to $1,700,000.*

Concept IIB is essentially a barge hull used in Concept I, with a section of decking left intact to support the flaring burner and associated equipment (air compressors, oil pump, water pumps for flame radiation abatement, connecting lines, generators, etc.). *The total cost of Concept IIB is assumed to be the barge hull cost ($500,000) + Concept I modification cost ($125,000) + cost of an Expro flaring burner (10,000 BPD capacity) and associated equipment (~ $1,500,000) which equals approximately $2,125,000.*

B.11.3 Concept III

The designers and manufacturers of the HIB Skimmer (Webster Barnes, Inc.) were directly consulted to determine the time and cost required to build a scaled-up version of the HIB skimmer hull. As described in Section B.1.3 of Appendix B, they have proposed two scaled-up versions of the HIB for the oil burning application, a 180-foot long version, and a 100-foot long version. *They estimate that the cost of the 180-foot device would be $1,800K, while the cost of the smaller device would be $710K. Making the designs modular for ease of transport will increase cost by 65%, making the cost of a modular 100 ft. HIB device $1,170,000.*

B.11.4 Concept IV

This system will probably have to be pre-constructed and pre-staged to be available for spill response. *The total cost of a system consisting of 150 feet of hose, a hydraulic hose reel, a blower, and a power pack is estimated at $14,000.* The cost breakdown for individual components is provided in Table B-7.

B.11.5 Concept V

Corrugated sheet metal is relatively inexpensive (approx $2/sq. ft. or $40 per section). Anchor bolts and re-bar may total another $10-$20 per section. Labor to cut-fabricate-assemble is estimated at one man-hour per section. *Total cost per section should be in the range of $100 per section or less. The total cost of a 500 ft. boom is $5,000.*

Table B-3. Tank Barge Market Report (Marcon International, Inc., June 1996)

Currently, Marcon has 124 inland tank barges available for sale, most of which are typical U.S. inland river units. We do though have a few foreign barges listed from both South America and Europe.

Following is a breakdown of inland barges listed:

INLAND TANK BARGES

Barrel Capacity

	Under 10000	**10000 20000**	**20000 30000**	**30000 40000**	**40000 50000**	**50000 60000**	**Unknown**
Total for sale	29	50	31	6	--	--	8
Average Age	1961	1960	1968	1971	--	--	1956
Average $/BBL	$20.91	$17.36	$12.60	$14.76	--	--	N/A

Number of barges officially for sale built within last 10/15 years: 2/3

Marcon also has listed and available for sale a total of 50 ocean and coastwise barges. Most of these are older single skin units with 9 being built since 1983 officially on the market.

OCEAN AND COASTWISE BARGES

Barrel Capacity

	Under 10000	**10000 20000**	**20000 30000**	**30000 40000**	**40000 50000**	**50000 Plus**	**Unknown**
Total for sale	10	9	10	3	4	5	9
Average Age	1974	1965	1966	1961	1961	N/A	1984
Average $/BBL	$31.27	$26.54	$11.63	$33.71	$16.50	N/A	N/A

In addition to those barges officially on the market for sale, we may be able to develop others direct from owners.

Tel: (360) 678-8880 -- Fax: (360) 678-8890 -- E-Mail: marcon@whidbey.net

Table B-4. Tank Barge Listings (Marcon International, Inc., June 1996)

FILE	TYPE	FLAG	LENGTH	BEAM	DEPTH	BUILT	BBL	PRICE
TB00250	Inland Tank Barge	U.S.	43.00	16.00	-	1980	250	$ 0
TB00500	Inland Tank Barge	U.S.	40.00	16.00	6.00	1989	-	$ 10,000
TB00857	Inland Tank Barge	U.S.	70.00	19.33	8.00	1952	857	$ 27,000
TB01930	Inland Tank Barge	U.S.	79.70	30.00	5.90	1956	1930	$ 50,000
TB02400	Inland Tank Barge	U.S.	100.00	30.00	7.20	1959	2400	$ 50,000
TB02796	Inland Tank Barge	U.S.	96.80	25.00	-	-	2738	$ 100,000
TB03100	Inland Tank Barge	U.S.	100.00	28.00	10.50	1932	2800	$ 132,500
TB03111	Inland Tank Barge	U.S.	110.00	30.00	7.00	1980	3000	$ 130,000
TB04098	Inland Tank Barge	U.S.	98.00	31.00	9.50	-	3214	$ 105,000
TB07019	Coastal Tank Barge	U.S.	192.00	35.00	8.00	1953	7000	$ 160,000
TB08027	Inland Deck Barge	U.S.	80.00	26.00	6.50	-	-	$ 52,500
TB09150	Ocean Tank Barge	Canadian	168.00	48.00	10.30	1966	9150	$ 335,000
TB09165	Inland Tank Barge	U.S.	165.00	35.00	10.50	1943	8700	$236,500
TB09177	Inland Tank Barge	U.S.	177.00	35.00	12.00	1948	8900	$ 265,000
TB10008	Inland Tank Barge	U.S.	170.00	44.00	12.00	1957	10000	$ 210,000
TB10009	Inland Tank Barge	U.S.	195.00	35.00	-	-	10000	$ 0
TB10035	Coastal Tank Barge	U.S.	195.00	35.00	11.00	1961	10700	$ 0
TB11175	Ocean Tank Barge	U.S.	175.00	35.00	12.00	1964	10700	$ 590,000
TB12003	Ocean Tank Barge	U.S.	200.00	40.00	12.50	1957	12000	$ 0
TB14196	Inland Tank Barge	U.S.	196.00	40.00	12.70	1941	14000	$ 415,000
TB19026	Ocean Tank Barge	Foreign	266.76	54.02	31.81	1992	-	$ 0
TB21007	Inland Tank Barge	U.S.	289.50	53.00	22.90	1956	21000	$ 265,000
TB21199	Coastal Tank Barge	U.S.	199.00	52.00	14.00	-	20800	$ 625,000
TB29260	Ocean Tank Barge	U.S.	260.00	52.00	18.75	1960	31316	$ 630,000
TB32240	Ocean Tank Barge		240.00	50.00	22.00	-	32000	$ 0
TB38000	Coastal Tank Barge	U.S.	297.50	43.10	-	1968	38000	$ 0
TB40002	Ocean Tank Barge	U.S.	351.50	60.00	18.20	1981	40000	$ 950,000
TB44001	Ocean Tank Barge	U.S.	275.00	50.00	20.20	1953	45495	$ 500,000
TB44275	Ocean Tank Barge	U.S.	275.00	50.00	20.00	1954	45456	$ 500,000
TB53297	Ocean Tank Barge	U.S.	296.00	60.00	22.00	1982	53499	$ 0
TB60280	Ocean Tank Barge	Foreign	280.44	89.97	17.99	1985	60000	$2,000,000
TB89293	Ocean Tank Barge	U.S.	380.00	84.75	30.50	1987	89293	$ 0

TB99000	FPSO	Australia	782.28	127.92	70.00	1989	-	$ 0

Table B-5. Cost Estimate for Modification of Barge - Concept I

Description of Modification	**Estimated Labor**	**Estimated Materials**	**Total**
Cut out tank tops in three aft centerline tanks	2 shipfitters * 2 days * 8 hrs * $100/hr = $3,200 2 welders * 1 day * 8 hrs * $100/hr = $1,600 2 riggers * 1 day * 8 hrs * $100/hr = $1,600	Miscellaneous materials and gases for cutting torches = $200	$6,600
Remove top 9 feet of four longitudinal bulkheads between five centerline tanks	2 shipfitters * 4 days * 8 hrs * $100/hr = $6,400 2 welders * 2 days * 8 hrs * $100/hr = $3,200 2 riggers * 2 days * 8 hrs * $100/hr = $3,200	Miscellaneous materials and gases for cutting torches = $200	$13,000
Engineering and design of bow modifications and baffles in centerline tanks	1 engineer * 1 week * 40 hrs * $250/hr = $10,000 1 engineering draftsman * 1 week * 40 hrs * $150/hr = $6,000	None	$16,000
Modify bow in accordance with design drawings	2 shipfitters * 5 days * 8 hrs * $100/hr = $8,000 2 welders * 5 days * 8 hrs * $100/hr = $8,000 2 riggers * 5 days * 8 hrs * $100/hr = $8,000	Miscellaneous materials and gases for cutting torches = $1,000 Steel = $5,000	$30,000
Fabricate and install baffles in centerline tanks in accordance with design drawings	2 shipfitters * 5 days * 8 hrs * $100/hr = $8,000 2 welders * 5 days * 8 hrs * $100/hr = $8,000 2 riggers * 5 days * 8 hrs * $100/hr = $8,000	Miscellaneous materials and gases for cutting torches = $1,000 Steel = $5,000	$30,000
Install insulation	2 insulators * 5 days * 8 hrs * $100/hr = $8,000	Ceramic tile = $10,000	$18,000
Install and remove temporary services for 1 week in shipyard	2 electricians * 1 day * 8 hrs * $100/hr = $1,600 2 pipefitters * 1 day * 8 hrs * $100/hr = $1,600 2 riggers * 1 day * 8 hrs * $100/hr = $1,600	Electricity, phone, water, sewage, trash disposal, and firefighting services = $1,000/day = $5,000	$9,800
Totals	$96,000	$27,400	$123,400

Table B-6. Cost Estimate for Modification of Barge - Concept II

Description of Modification	**Estimated Labor**	**Estimated Materials**	**Total**
Cut out tank tops in three aft centerline tanks	2 shipfitters * 2 days * 8 hrs * $100/hr = $3,200 2 welders * 1 day * 8 hrs * $100/hr = $1,600 2 riggers * 1 day * 8 hrs * $100/hr = $1,600	Miscellaneous materials and gases for cutting torches = $200	$6,600
Remove top 9 feet of four longitudinal bulkheads between five centerline tanks	2 shipfitters * 4 days * 8 hrs * $100/hr = $6,400 2 welders * 2 days * 8 hrs * $100/hr = $3,200 2 riggers * 2 days * 8 hrs * $100/hr = $3,200	Miscellaneous materials and gases for cutting torches = $200	$13,000
Engineering and design of bow modifications and baffles in centerline tanks	1 engineer * 1 week * 40 hrs * $250/hr = $10,000 1 engineering draftsman * 1 week * 40 hrs * $150/hr = $6,000	None	$16,000
Modify bow in accordance with design drawings	2 shipfitters * 5 days * 8 hrs * $100/hr = $8,000 2 welders * 5 days * 8 hrs * $100/hr = $8,000 2 riggers * 5 days * 8 hrs * $100/hr = $8,000	Miscellaneous materials and gases for cutting torches = $1,000 Steel = $5,000	$30,000
Fabricate and install baffles in centerline tanks in accordance with design drawings	2 shipfitters * 5 days * 8 hrs * $100/hr = $8,000 2 welders * 5 days * 8 hrs * $100/hr = $8,000 2 riggers * 5 days * 8 hrs * $100/hr = $8,000	Miscellaneous materials and gases for cutting torches = $1,000 Steel = $5,000	$30,000
Install insulation	2 insulators * 5 days * 8 hrs * $100/hr = $8,000	Ceramic tile = $10,000	$18,000
Fabricate and install foundation for stacks and incinerator	2 shipfitters * 5 days * 8 hrs * $100/hr = $8,000 2 welders * 5 days * 8 hrs * $100/hr = $8,000 2 riggers * 5 days * 8 hrs * $100/hr = $8,000	Miscellaneous materials and gases for cutting torches = $1,000 Steel = $5,000	$30,000
Fabricate and install stacks and incinerator	2 shipfitters * 5 days * 8 hrs * $100/hr = $8,000 2 welders * 5 days * 8 hrs * $100/hr = $8,000	Miscellaneous materials and gases for cutting torches = $1,000 Steel = $15,000	$40,000

	2 riggers * 5 days * 8 hrs * $100/hr = $8,000		
Install and remove temporary services for 2 weeks in shipyard	2 electricians * 1 day * 8 hrs * $100/hr = $1,600 2 pipefitters * 1 day * 8 hrs * $100/hr = $1,600 2 riggers * 1 day * 8 hrs * $100/hr = $1,600	Electricity, phone, water, sewage, trash disposal, and firefighting services = $1,000/day = $10,000	$14,800
Totals	$144,000	$49,400	$193,400

Table B-7. Cost Estimate for Air Bubbler System - Concept IV

Item	Description	Approx. Unit Cost	Approx. Weight (lb)	Quantity	Extension Cost
Air Hose	4" diameter fabric hose w/galvanized chain and quick link end connectors	$20.00	~900 lb.	150 ft	$3,000
Hose Reel	Hydraulic hose reel, dimensions 50 in X 50 in X 50 in	$4,000	~ 300 lb.	1	$4,000
Blower	Output equals 1500 cfm, runs with the same power pack as hose reel.	$3,000	~ 650 lb.	1	$3,000
Power Pack	Diesel Driven hydraulic supply to run blower and hose reel, 9HP, 75 GPM hydraulic output, explosion proof	$4,000	~ 200 lb.	1	$4,000
Total			~2050 lb.		$14,000

B.12 Inspection, Certification and Approval

B.12.1 through B.12.3 Concepts I through III

The inspection and certification requirements for Concepts I, II and III are not clearly specified in any one regulation or set of guidelines due to the unique nature of the devices. Depending on the design configuration of each concept and the perspective of the inspecting and certifying agency (e.g., the Coast Guard, EPA), the devices may be viewed as tank barges, oil spill recovery devices (OSRVs), or floating incinerators with each device governed by its own set of regulations. In general, the following guidelines and regulations may apply for each.

Tank Barges: The requirements for tank barges are specified in 46 CFR Subchapter D and would be applied to the barge hulls in Concepts I and II prior to conversion to an oil burning device. However, the current Coast Guard interpretation of a functional "tank vessel" is a vessel which has an oil-holding capacity in excess of 20% of its deadweight tonnage. *As Concepts I and II are no longer carrying oil in an amount anywhere near this quantity (assuming that it is being continuously burned), it becomes questionable whether the Subchapter D requirements strictly apply.*

Oil Spill Recovery Vessels - OSRVs have presented an inspection challenge for the U.S. Coast Guard for a number of years. The original approach was to treat them as "tank barges" and apply the 46 CFR Subchapter D criteria. This, however, caused a number of inconsistencies and problems for shipbuilders producing these devices to the extent that development and production was discouraged (as described by Bianchi, 1993). To adjust the inspection and certification criteria for OSRVs, the Coast Guard has issued a series of Policy Letters (CG-MVI, 1991; CG-MVI, 1993 and CG-MVI, 1995) which provide additional guidelines on how various Subchapters of 46 CFR are to be applied to OSRVs. The most recent directive, Commandant, MVI Policy Ltr No. 01-95 of Feb. 13, 1995, provides detailed guidance for three categories of OSRVs: Skimming Vessels and Barges less than 15 GT (gross tons), Small Recovery Vessels greater than or equal to 15 GT but less than 100 GT, and Larger Recovery Vessels greater than 100 GT but less than 500 GT. OSRVs over 500 GT carrying oil are inspected according to Subchapter D as tank vessels. An important consideration in inspecting OSRVs is the grade of oil that is being recovered. OSRVs that handle more volatile oils (Grade B&C) must have intrinsically safe (non-sparking) machinery and combustible gas monitoring devices. As volatility of the oil is a desirable quality for the purposes of burning, it is assumed that Concepts I through III must be certified to operate in these environments.

Incinerators - The Oil Programs Office at EPA Headquarters was contacted to determine how Concepts I, II and III might be regarded by the EPA - either as an extension of in-situ burning (an oil spill countermeasure) or as marine incineration devices. The response (personal communication from Mr. Michael Nichols) was that the devices would most likely be regarded as incinerators, and that an EPA permit would be required. The permitting requirements for hazardous waste incinerators are specified in 40 CFR 260, 264 and 265. 40 CFR 260.1 defines incinerator as "any enclosed device that uses controlled flame combustion". It appears that Concepts IIA and IIB would meet this definition; it is not as clear for Concepts I and III. The requirements for incinerators in 40 CFR 264 and 265 are somewhat extensive but clearly state that incinerators processing hazardous wastes classified as such solely because of ignitability (containing no toxic components) are exempt from many of the requirements (except initial waste analysis and closure requirements); hence obtaining a permit from EPA may be a straightforward process.

In summary, the inspection, certification and approval criteria for Concepts I, II and III will *probably be determined on a case-by-case basis depending on the ultimate design and configuration of each device. It is possible that Concepts I and II will have to meet some of the requirements of Subchapter D as they are initially tank vessels and exceed 500 gross tons, the cutoff for relaxed requirements under the latest Coast Guard OSRV policy directives. It is clear that Concepts IIA and IIB will be viewed as hazardous waste incinerators by EPA and will have to meet permitting requirements under 40 CFR 264-265. This may not be the case for Concept I and Concept III, but this will be subject to EPA interpretation. Concept III may be subject to the Coast Guard OSRV requirements for small or large recovery vessels, depending on the gross tonnage of the device. Concepts I, II and III should meet the requirements for operation in Grade B & C oils. It is also clear that inspection and certification requirements will be greatly simplified if the devices are unmanned during operation. In general, it can be assumed that all of the devices described in Concepts I, II and III could be inspected, certified and ultimately approved for use.*

B.12.4 and B.12.5 Concepts IV and V

Inspection/certification of the systems is not required. Use will have to comply with EPA and OSHA criteria for spill response and local air quality regulations.

Appendix C

Transport, Deployment and Operational Considerations - Detailed Discussion and Calculations

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Appendix C
Deployment and Operations Considerations

This appendix provides a more detailed discussion and calculations to support findings on the engineering design and construction feasibility of the various alternative concepts for burning of oil spills outlined in Section 6 of this report. Where appropriate, the findings in Section 6 are annotated to reference specific sections of this appendix which provide the descriptions, calculations, figures or tables to support the overall feasibility rating assigned for a specific issue and specific concept. The references cited are contained in Appendix E.

C.1 Transport, Assembly and Deployment

Oil spill response equipment must be moved from the storage location to the spill site in time to operate within the conditions for which the specific technique or device was designed. This time period of optimal effectiveness is generally described as the "window of opportunity" for the countermeasure or cleanup technique. The "window of opportunity" for conducting in-situ burning using the fire-resistant boom is of limited duration. Spilled oil becomes weathered and emulsified over time making it more difficult to burn. The Alaska Regional Response Team guidelines for burning recommend less than 2-3 days of weathering exposure, and less than 25% water content (emulsification) for optimal ignition and burn efficiency. Depending on the type of oil, emulsified oil with a water content greater than 25% can be difficult to ignite; oil with a water content above 75 % is impossible to ignite with conventional ignition systems. This was the situation encountered in the EXXON VALDEZ spill in which a storm emulsified the oil on day 3 of the spill, precluding any further burning operations.

To bring one of the devices considered into service at the scene of an oil spill requires three distinct evolutions:

- **Mobilization and transport from the storage location to the equipment staging area for the spill response.**
- **Assembly and outfitting at the staging area particularly where the device is transported in sections and components by land or air transport.**
- **Deployment from the staging area to the scene of the spill which may be a considerable distance for offshore spills or spills in remote areas.**

Only after all three of these evolutions have been completed is the device ready to go into service.

For effective burning, it is assumed that these three evolutions must be completed within the Tier II response time (36 hours) specified under Coast Guard regulations. Tier II response is appropriate because the "window of opportunity" for burning can be as short

as 72 hours.

The modes and time estimates for mobilization, transport, assembly and arrival on scene are discussed in some detail below. The discussions are summarized in Table C-1 which provides the total time to arrive on scene both in hours and expressed as the maximum distance the device can be located from the spill site and still meet the Tier I (12 hr), Tier II (36 hr) and Tier III (60 hr) response criteria.

Table C-1 - Mobilization, Transport and Deployment Estimates for Concepts I, II and III.

	CONCEPT 1	**CONCEPT 2**	**CONCEPT 3**
Get response team to barge, rig device for towing over water, and acquire tug for towing (Concept I, & II). Get response team to equipment and load it for overland transport (Concept 3).	**6 hrs**	**6 hrs**	**6 hrs.**
Overland transport speed			**30 kts**
Time to load and unload the air transport vessel (including truck travel to and from air transport)			**6 hrs**
Air transport speed			**400 kts**
Time to assemble or rig the device once it has arrived at staging area	**1 hr**	**1 hr**	**6-10 hrs**
Estimated tow speed to site	**7 kts**	**7 kts**	**10 kts**
Time to deploy after arrival on site	**1 hr**	**1 hr**	**1 hr**
Maximum distance from spill site to achieve Tier 1 - 12 hrs	**35 NM**	**35 NM**	**130 NM** **(no air transport)** **(Assume spill is 20 NM off shore)**
Maximum distance from spill site to achieve Tier 2 - 36 hrs	**203 NM**	**203 NM**	**9,200 NM** **(Assume spill is 20 NM off shore)**
Maximum distance from spill site to achieve Tier 3 - 60 hrs	**371 NM**	**371 NM**	**18,800 NM** **(Assume spill is 20 NM off shore)**

C.1.1 and C.1.2 Concepts I and II

The transport, assembly and deployment of the barge devices in Concepts I and II are straightforward, albeit time consuming. The devices can only be transported by sea using a tug as the tow vessel. Calculations using the PROLINE software package indicate that the required horsepower of the tug should be at least 12,500 brake horsepower (BHP). This means that the tug will have to be a larger oceangoing vessel. The modified barge devices

in Concepts I and II can be transported by sea with a maximum tow speed of 7 knots. The assembly time for Concepts I and II assumes that the barge has been fully modified and outfitted prior to reaching the staging area. On-scene assembly and deployment will involve inspection and checking of the various systems that might be included (e.g., CO2 fire-suppression system, ferrocene additive distribution system), rigging of the collection boom outriggers, and rigging the tow lines and secondary collection boom. Once at the spill site, it is assumed that the barge can be ready to begin operation within an hour. ***Total mobilization, including the acquisition of a tug, and assembly and rigging of the device for tow, is estimated at 6 hrs for Concept I and 10 hrs for Concept II. This assumes that a tug is available near the storage location of the device. In order to be able to respond to a spill within 36 hrs (i.e., meet USCG Tier II response criteria) the barge can be located no further than 203 NM (nautical miles) from the spill site.***

C.1.3 Concept III

The underlying assumption for Concept III is that the device will be modular, that is, it can be broken down in sections amenable to overland transport by truck or by air (e.g., C-130 or C-5A cargo aircraft) to the staging site. Assembly time at the staging area depends on the final configuration of the device which has not been fully determined at the conceptual design stage. ***However, it is reasonable to expect that the HIB-like device can be assembled, outfitted and launched within 6-10 hours. Because of the time saved in overland and air transport, this time delay is not of major concern. Once assembled, the device can be towed to the spill site by a tug of appropriate size. Assuming that air transportation is available and that the spill is 20 NM offshore, the device can be stored up to 9,200 NM from the spill site and still meet the Tier II response criteria.***

C.1.4 and C.1.5 Concepts IV and V

Because Concepts IV and V are comprised of several smaller, easy-to-handle components, many of the loading and transport assumptions used for Concept III with regard to overland and air transport will apply. The devices can be easily loaded on a flatbed truck or commercial or military cargo plane.

For Concept IV, system components (generator, blower and hose reels) can be transported to the spill site in sections, either by helicopter or small boat. Mobilization, assembly and deployment times will be minimal (perhaps 3 hours). Accordingly, the system components can be stored up to 10,000 miles from the spill site and still meet the Tier II criteria.

Sections of the corrugated metal fence boom that comprise Concept V are small enough to be loaded and handled by a single person. Transport is easily accomplished by truck, small, shallow-draft boat or helicopter. Assuming that the fence boom sections have been pre-fabricated prior to transport to the staging area, assembly and deployment at the

staging area is minimal, perhaps 1 to 3 hours depending on the size of the enclosure being constructed. As the components are relatively inexpensive, it is assumed that they can be stored at several locations around the country, or even fabricated on scene, as long as a local source of materials (corrugated metal and the necessary hardware) has been identified in advance. *Accordingly, the system components can be stored up to 10,000 miles from the spill site and still meet the Tier II criteria.*

Deployment of the air-bubbler and fence boom systems in the field will be accomplished by small boats and by personnel entering the water with hip waders. If the system can be deployed in tidal areas at low tide without serious damage to the marsh or tidal creek bottom, this may be preferable. The strategy here is to capture and burn the oil on the outgoing tide. Re-deployment should be easily accomplished in six hours, thus allowing re-positioning during low tide of a semi-diurnal tidal cycle.

C.2 Tending on Scene

In many respects, conducting burning operations using the alternative approaches in Concepts I through V will require the same planning process and procedures as currently defined for in-situ burning using fire-resistant boom. These procedures are described in detail by Buist *et al.* (1994a). Certain modifications to the procedures will be required in using the devices in Concept I through Concept V as described below.

C.2.1 and C.2.2 Concepts I and II

Tending on scene will require the use of towing vessels, and possibly a small auxiliary vessel to check the condition and operation of the barge, remove residue, inspect secondary collection booms, and be available to deal with emergencies. The towing vessels for Concepts I and II will probably be larger offshore tugs or possibly offshore supply vessels, with sufficient horsepower to transport the burning device to the scene but sufficient maneuverability to keep the device on station at speeds below 1 knot. This slow speed maneuverability is required to keep the device more or less stationary with respect to a continuous, fixed, oil spill source (particularly a blowout), the primary application for which Concepts I and II are designed. *As operation of Concepts I and II may require being on station for several days, the towing vessels must have the necessary endurance and crew accommodations to support this.*

Effective operation will require that the device be kept in the thickest portion of the oil slick to intercept the maximum quantity of oil. *Periodic spotting by aircraft, ideally a helicopter, may be required to locate heaviest concentrations of oil and assist in positioning the barge*. It is expected that operation will be restricted to daylight hours, unless airborne surveillance and the stability of the spill source (in both volume and transport of the slick) allow for night operations.

An auxiliary vessel will be required for checking the condition of the barges, tow lines, and booms; monitoring downwind concentrations of contaminants as required by environmental monitoring protocols; and moving personnel and equipment to and from the towing vessels as necessary. **The auxiliary vessel can also serve as an observation platform for officials and media.**

The handling of ice or floating debris may be a problem in certain situations. ***For Concepts I and II, smaller pieces of ice and debris can be processed through the incineration device without damaging it because of the large size of the bow opening and the rugged construction of the device. Larger pieces of ice and debris can be kept out of the burn area by installing a metal grating, mounted at an angle in front of the inclined plane oil collection device, such that slightly buoyant or neutrally buoyant debris passes under the barge hull.*** **Larger pieces of ice or buoyant debris stopped by the grating may cause blockage of the opening, restricting the flow of oil into the device. Accordingly, operation in heavy ice or debris areas may be prohibited.**

C.2.3 Concept III

The tending requirements for Concept III will be very much the same as for Concepts I and II with the exception that the towing vessels need not be as large, as Concept III will be substantially smaller than Concepts I and II. **It is also likely that Concept III will be more maneuverable so that it can be actively towed through the oil slick to increase oil encounter rate in the same manner as with fire-resistant booms.**

Because of the smaller size of the Concept III hull, ice and heavy debris may be more of a problem than with the Concept I and II devices. ***Installation of a metal grating, set at an angle, will keep ice and debris out of the burn area, and allow small debris to pass under the hull.*** **In a somewhat similar design for an Arctic Incinerator Barge (Glosten Associates, 1991), debris removal was enhanced by a series of rotating discs mounted in the metal grating. The discs were hydraulically driven. Although such an arrangement is technologically feasible, the level of complexity and amount of machinery runs contrary to the goal of a simple, modular, easily-transportable design. The limited capability in ice appears to be a reasonable trade-off for the sake of simplicity.**

C.2.4 and C.2.5 Concepts IV and V

Tending will be limited when the burn is in progress, with personnel in boats or onshore at a safe distance from the burn. For Concept IV, the position and configuration of the bubbler hose may have to be adjusted for changing flow conditions or with each tidal cycle to capture oil on the incoming or outgoing tide. For Concept V, the condition of the fence boom should be assessed at various intervals**. If significant deterioration of the fence boom sections is observed, burning will have to be suspended and these sections replaced. For Concepts IV and V, it is assumed that operations will be of shorter duration (perhaps a day or two) and restricted to daylight hours only. Although spotter aircraft are not absolutely required, they will be valuable in the initial positioning of the devices, for conducting environment monitoring, and maintaining site safety and security.** ***Emergency firefighting and fire-suppression teams should be standing by to deal with emergencies.***

C.3 Simplicity/Reliability

The simplicity and reliability of the technique or device go hand in hand. Simplicity and reliability are generally enhanced by the absence of machinery and sophisticated auxiliary systems which may be subject to failure, thereby requiring temporary suspension of the burn to allow repairs. Simplicity and reliability also reduce the amount of time in assembling and rigging the device, and the requirement for having maintenance personnel on scene.

C.3.1 and C.3.2 Concepts I and II

Concepts I and II will vary in simplicity and reliability as a function of the ancillary systems that are used with each device. A simple, no-moving-parts version of either concept will be the most desirable option. Some form of water cooling system will probably be required. **Airflow enhancement, onboard ignition, the addition of emulsion breaking and smoke suppression additives will add complexity as the machinery, hydraulics, and control devices are introduced to support each system. Special provisions will be required to protect machinery and equipment from the heat and flame of the burn itself. In some cases, redundancy of critical systems will be required to ensure reliability. Ancillary systems such as airflow enhancement blowers, aerators in the burn compartment, and emulsion breaker and smoke suppression distribution systems will achieve higher levels of burn efficiency and environmental protection at the expense of reliability and cost.** ***Probably the most efficient but complex system will be the flaring burner option in Concept IIB, which will require a full suite of supporting generators, pumps, and air compressors, as well as the burner head itself. The complexity of this system will require full-time monitoring of the operation either remotely or perhaps aboard the barge itself.***

C.3.3 Concept III

Concept III will probably be much simpler than Concepts I and II. The smaller size of the device required for transportability will preclude the addition of large amounts of machinery. **The most attractive feature of the HIB skimmer design is its no-moving-parts design which relies on the movement of the device through the water to collect the oil.** ***Ancillary systems for the device will probably be limited to a simple propane ignition system and some form of water cooling system with the water pumps mounted on the towing vessel or perhaps on a trailing machinery float*** **(such as with the Coast Guard High Seas Skimming Barrier). It is expected that this device will be highly reliable.**

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C.3.4 and C.3.5 Concepts IV and V

Reliability is not as important an issue for Concepts IV and V as it is with Concepts I - III, as continuous operation is not anticipated. ***The auxiliary machinery associated with Concept IV includes a simple power pack and blower which will be highly reliable.*** **As the machinery is located onshore away from the burn, it can be continuously monitored.** ***Concept V is the simplest and most reliable system; any fence boom sections that show deterioration can simply be replaced.***

C.4 Operational Safety

The operational safety considerations for Concepts I through V are generally similar to those specified for in-situ burning using fire-resistant boom and for uncontained burning in marshes and on shorelines. A general description of these safety considerations is provided by Buist *et al.* (1994a). Detailed guidance for the preparation of site safety plans for in-situ burn operations was recently published by the National Response Team, Science and Technology Committee (NRT, 1997). The discussion below summarizes the general safety issues and highlights safety considerations that are specific to employing the devices in Concepts I - V.

C.4.1 through C.4.3 Concepts I, II and III

***The primary safety consideration for employing Concepts I, II and III is protecting personnel onboard the towing and attending vessels, and any vessels that may be in the vicinity of the burn.* It is assumed that there are no personnel onboard the burn devices as this will greatly increase the concerns and precautions that must be taken, and in fact may run contrary to current marine safety and worker safety regulations. The only possible exception may be Concept IIB (the flaring burner option), where the burn process itself is completely contained and controlled.**

According to NRT guidelines, a Site Safety and Health Supervisor will be designated to monitor and assess the effective implementation of the Site Safety Plan throughout the burn process. In addition, an individual on each of the tow vessels should be designated to monitor and track the progress of the burn and the condition of the burn vessel. *Positioning of the tow vessel will be a major concern. The tow vessel should remain upwind and a safe distance away from the burning device.* For burning operations using fire-resistant booms, the prescribed safe distance is five fire diameters away from the center of the burn. As the burn is somewhat contained with Concepts I - III, this distance is probably adequate for protection from flame radiation.

A larger concern for the towing vessels is having enough room to maneuver in the event of an emergency, without colliding with the device. In addition to remaining a proper distance from the burn device, the towing vessels must also remain a sufficient distance from the spill source to avoid toxic gases (as with a blowout) and prevent any flashback to the source. *Personnel on board the tow vessels must also be mindful of toxic and explosive vapors from the slick itself.* Onboard monitoring of toxic and combustible gases is recommended.

Protective equipment such as respirators should be available in the event of emergency but not routinely worn.* The current philosophy on in-situ burn safety is that personnel requiring protective clothing and equipment are too close to the oil source or burn operation and should be immediately removed. *Procedures for the termination of burn operations and

departure from the area should be fully defined and exercised before the burn begins. **A plan must be developed for retrieving the barge if a tow line parts or if a towing vessel experiences an engine or steering casualty. An important consideration for Concepts I and III is that dropping the tow line will not automatically terminate the burn as with in-situ burning using fire boom. If systems are installed onboard the burn vessels for fire suppression/extinguishment, these should be tested before the burn begins. Safety procedures for deploying and retrieving the barge/device, particularly with respect to boarding the barge, should be developed.**

C.4.4 and C.4.5 Concepts IV and V

Site safety plans for the application of Concepts IV and V will be developed using the NRT guidelines. A **Site Safety and Health Supervisor should be designated and personnel involved in the burn operation properly trained (via Hazardous Worker Program, HAZWOPR, training) and fully briefed on the objective and procedures for the burn. The highest risk is posed by uncontrolled spread of the fire to adjacent marsh and shoreline areas. There are certain situations where in-situ burning in confined areas will pose the danger of the fire spreading beyond the planned burn area.** ***The potential for unbridled oil burning is a possible hazard with the air bubbler curtain concept which is may be used in inland areas near marsh, trees, and other flammable items.*** **The primary fire-suppression method for the air curtain is to shut down the air, thus allowing the oil to disperse to the point where the fire goes out. According to Allen (1993), there are times when the oil will continue to burn even when the oil barrier (collection boom or bubbler curtain) is removed.** ***Foam firefighting equipment should be made available if the safety personnel determine that there is a possibility of continued oil burning after the air bubbler system is shut down.***

Personnel should remain a safe distance from the flame (determined to be 5 pool diameters from the edge of the burn). **Emergency evacuation equipment and procedures are required. Respirators and protective clothing should be available but again not worn as a matter of routine. The proximity of nearby residences and commercial facilities should be carefully noted. The amount of bubbler hose and fence boom deployed should be limited to restrict the burn to a manageable size. Several smaller burns may be safer and more effective than a single large burn.**

C.5 Environmental Monitoring

Procedures for environmental monitoring during in-situ burn operations have been established within the ISB Pre-Approval Guidelines for several RRTs and are being finalized at the NRT level by the Science and Technology Committee (NRT, 1998). These same criteria apply to the five concepts being proposed as alternative approaches to in-situ burning.

The primary concern with regard to impact on human populations is air quality degradation caused by the burn emissions. The burning oil produces toxic combustion gases downwind from the burn; however, these rapidly dissipate within a few hundred meters of the burn and beyond a kilometer will be diluted below levels of concern. Although these gases may pose a hazard to response personnel, they are not likely to threaten general populations downwind of the spill. The main hazard to human populations downwind is the concentration of particulate matter (soot) in the particle size

range of 10 microns or less (described as the PM-10 level). The National Response Team recommends a maximum allowable concentration of 150 micrograms per cubic meter of PM-10 over an hour. A monitoring program should be instituted in the vicinity of the burn to ensure that these levels are not exceeded.

Other environmental concerns that should be considered and monitored are the impact of the heat and flame, and the operation as a whole (e.g., the activity and noise) on surrounding wildlife populations. Another consideration with nearshore and inshore burning is the aesthetic impact and its effect on recreational use of the area. Considerations specific to each of the alternative approaches are listed below.

C.5.1 through C.5.3 Concepts I, II and III

The primary environmental consideration is the PM-10 concentration downwind when the burn operation is conducted close enough to shore to be of concern for human populations. *The PM-10 concentration can be monitored from an auxiliary boat taking samples along the shoreline or by monitors located on the shore itself.* The major dangers to marine resources are the possible entrapment of marine species in the oil collection boom and the hazard posed by the towing vessels. *The aircraft and vessels conducting oil slick surveillance should be mindful of any marine mammals spotted in the area and the towing vessel - burn vessel maneuvered away from marine mammals as required.* Burn residue should not be a problem as it is ideally retained aboard the burn device.

C.5.4 and C.5.5 Concepts IV and V

Environmental impact is more of a consideration with Concepts IV and V, as these burn operations will be conducted nearshore and onshore, possibly in proximity to sensitive environmental resources and to human populations in residential and commercial areas. *PM-10 concentrations should be monitored downwind to ensure that the NRT recommended limits are not exceeded. Traffic through sensitive environmental areas to reach the spill site should be minimized with the most benign forms of access utilized (e.g., small boat or helicopter)*. The impact of heat, noise, and combustion gases on local wildlife populations should be assessed as well as the danger of secondary ignition of surrounding areas. Emergency firefighting equipment should be kept on scene in the event the fire spreads beyond the containment area.

C.6 Cleaning/Disposal

Once the burn operation has been completed, the devices and equipment for Concepts I through V will have to be demobilized, cleaned, and any oil burn residue and contaminated material properly disposed of according to existing hazardous waste disposal regulations. The level of difficulty associated with this will vary with each concept as described below.

C.6.1 and C.6.2 Concepts I and II

The barge devices must be fully cleaned in a shipyard or drydock following use. This will probably be specified in the Coast Guard Certificate of Inspection, as is the usual practice

with oil spill recovery vessels which must be gas freed and cleaned after each oil recovery operation. Residual oil will be removed with steam cleaning and detergent, with the effluent recovered and disposed of. ***The cost of this procedure depends on the specific concept employed (I, IIA or IIB) but will be (at a minimum) roughly the same as cleaning and gas freeing a tank barge after it is used to store and transport a heavy or emulsified oil recovered during spill response operations. This cost generally ranges from $5,000 to $10,000 for a larger, oceangoing barge.***

C.6.3 Concept III

The device described by Concept III will have to be completely cleaned following use, but the modular design and transportability of the device will allow disassembly and transport in sections to a cleaning site. **This will preclude the necessity for drydocking and may decrease the cost of cleaning substantially. Sections of the device subject to thermal or mechanical failure will have to be replaced.**

C.6.4 and C.6.5 Concepts IV and V

The cleaning of the air bubbler system and the fence boom can be accomplished in the same manner as conventional booms, skimmers, and shoreline cleanup equipment. **Because the components are small and can be easily handled and transported, they can be transported to a dedicated cleaning facility some distance from the spill site. This may reduce the cost associated with cleaning and disposal of residue and cleaning effluent.**

C.7 Refurbishment

C.7.1 and C.7.2 Concepts I and II

The level of refurbishment, and hence the cost, for Concepts I and II will depend on the configuration of the device, the number of ancillary systems (e.g., fire-suppression systems, smoke suppression additive and emulsion breaker distribution systems). For Concept I, refurbishment will probably include inspection of the material and structural integrity; replacement of damaged insulating material; cleaning and repair of distribution lines for CO2, cooling water, and additives; and overhaul and servicing of any machinery onboard (pumps and generators). For Concept IIA, refurbishment will also include overhaul and cleaning of the airflow/burn enhancement equipment (e.g., blowers, air injection systems, and stacks). The refurbishment of Concept IIB will be straightforward including cleaning and gas freeing of the oil containment tank, and overhaul and maintenance of the flaring burner system, including burner heads, air compressors, oil and water pumps, and generators. Ideally the flaring burner components can be temporarily removed from the

barge hull for servicing. For Concepts I and II, the oil concentration booms will also have to be refurbished or replaced. *If there is substantial heat damage or mechanical failures experienced during the burning operation, refurbishment requirements may escalate to the point where a complete overhaul is required. The cost of such an overhaul may be a significant percentage of the initial cost of the device (25% - 50%).* At some point, scraping the hull and starting over may be the most cost effective option.

C.7.3 Concept III

Refurbishment of Concept III will require inspection of the burn tank and replacement of any damaged insulation. The flotation hull members will have to be inspected but should be relatively undamaged by the burn; structural integrity will be the key issue after extended service at sea. The modular design will allow disposal of the burn tank if it is heavily damaged, while retaining the flotation hulls and other components for reuse. *Refurbishment of the device after extended deployment may cost from 25% to 50% of the original construction cost depending on the severity of damage.* The oil concentration booms will also have to be refurbished or replaced.

C.7.4 Concept IV

Portions of the air bubbler system such as the air blower, galvanized chain, and cleanable sections of hose can be refurbished and reused. Damaged sections will be replaced.

C.7.5 Concept V

Sections of the fence boom not subject to heat stress can be reused in several locations during a single response effort. At the conclusion of the response effort, the fence boom will likely be cleaned and disposed of as scrap metal.

Appendix D

Summary of Oil Spills Used in Applications Hindcast

Summary of Spills Used in Applications Hindcast

Introduction

The following is a compilation of past spills that were reviewed to determine the overall applicability of the five alternative burning concepts developed during the study. For each spill, the important characteristics are listed, the sequence of events summarized, and an assessment made of the applicability of Concepts I - V to the specific spill, or a similar spill with a slightly different set of characteristics. Much of the information used was taken from the NOAA HAZMAT compendium of <u>Oil Spill Case Histories - 1967-1991</u> (NOAA, 1992), and specific papers, most of which are found in the various proceedings volumes from the Biennial International Oil Spill Conferences (1969-1997). Specific references are listed at the end of this Appendix. The spills reviewed and evaluated are listed in Table D-1 below.

Table D-1 Listing of Major Spills Surveyed for Applications Hindcast

Name of Spill	**Date**	**Location**	**Oil Type**	**Amount**
ALVENUS	**7/30/84**	**Cameron, LA**	**Venezuelan Merey and Pilon crude oil**	**65,000 bbl**
AMAZON VENTURE	**12/86**	**Savannah River**	**No. 6 fuel oil**	**11,904 bbl**
AMERICAN TRADER	**2/7/90**	**Huntington Beach, CA**	**Alaska North Slope crude**	**9,458 bbl**
AMOCO CADIZ	**3/16/78**	**Brittany, France**	**light crude oil**	**1,619,048 bbl**
APEX **Barges**	**7/28/90**	**Galveston Bay, TX**	**catalytic feedstock oil**	**16,476 bbl**
ARCO ANCHORAGE	**12/21/85**	**Port Angeles, WA**	**Alaska North Slope crude**	**5,690 bbl**
Ashland Oil Spill	**1/2/88**	**Floreffe, PA**	**No. 2 diesel fuel**	**23,810 bbl**

ATLANTIC EMPRESS	**7/19/79**	**Caribbean Sea**	**crude oil**	**3,500,000 bbl (potential)**
BRAER	**1/5/93**	**Garths Ness, Shetland Islands**	**Norwegian Gullfaks crude oil**	**532,400 bbl**
Brunswick Naval Air Station	**3/26/93**	**Brunswick ME**	**JP-5 Aviation Fuel**	**1500 bbl**
BUFFALO 292	**3/18/96**	**Houston Ship Channel**	**IFO 380**	**3,000 bbl**
BURMAH AGATE	**11/1/79**	**Galveston**	**Nigerian crude**	**254,761 bbl**
Chevron Main Pass 41	**2/10/70**	**Gulf of Mexico**	**Louisiana crude**	**65,000 bbl**
Colonial Pipeline, Enoree River	**12/91**	**Fountain Inn, SC**	**No. 2 fuel oil**	**13,000 bbl**
Ekofisk Bravo	**4/22/71**	**North Sea off Norway**	**Ekofisk Crude**	**202,380 bbl**
ESSO BAYWAY	**1/28/79**	**Port Arthur, TX**	**Light Arabian Crude**	**6,500 bbl**
Exxon Bayway, Arthur Kill	**1/2/90**	**Arthur Kill NY**	**No. 2 heating oil**	**13,500 bbl**
Exxon Pipeline Company	**1/7/92**	**Copano Bay TX**	**Texas light crude**	**2950 bbl**
EXXON VALDEZ	**03/24/89**	**Prince William Sound, AK**	**North Slope Crude**	**262,000 bbl**
Hasbah	**10/2/80**	**Saudi Arabia**	**heavy crude oil**	**50,000 bbl**

IXTOC I Blowout	6/3/79	Bay of Campeche	Heavy crude oil	3,522,400 bbl
KIRKI	7/21/91	Australia	light crude oil	111,257 bbl
KURDISTAN	3/15/79	Cabot Strait, Canada	Bunker C	44,000 bbl
MEGA BORG	6/8/90	Gulf of Mexico	Angolan Palanca crude	92,857 bbl
NESTUCCA	12/22/88	Grays Harbor, WA	Bunker C	5,500 bbl
NORD PACIFIC	7/13/88	Corpus Christi, TX	North Sea crude	15,350 bbl
Norwuz Oil Field	02/10/83	Persian Gulf off Iran	Norwuz crude	1,900,000 bbl
PAC BARONESS	9/21/87	Point Conception, CA	Bunker oil	9,200 bbl
PRESIDENTE RIVERA	6/24/89	Delaware River	No. 6 oil	7,130 bbl
PUERTO RICAN	11/3/84	Off San Francisco, CA	lube oil and additives	38,500 bbl
Santa Barbara Blowout	1/28/69	Off Santa Barbara, CA	California crude	100,000 bbl
Santa Clara River	1/17/94	Southern California	San Joaquin blended crude	4,600 bbl

SEA EMPRESS	2/15/96	Milford Haven, U.K.	Forties Blend crude oil	45,483 bbl
Shell Oil, Martinez, CA	4/23/88	San Joaquin Valley, CA	crude	9,400 bbl
Shell Platform 26	12/1/70	Gulf of Mexico, LA	LA crude	58,640 bbl
Trinmar Marine Well 327	8/8/73	Gulf of Paria	Venezuelan crude	36,650 bbl
YUM II/Zapoteca	10/10/87	Bay of Campeche Mexico	Light crude	58,640 bbl

Summary of Spills Used for Applications Hindcast

ALVENUS

Date of Spill: 07/30/84
Location of Spill: Calcasieu River, 11 miles SE of Cameron, LA
Volume of Spill: 65,000 bbl
Cause of Spill: Tanker Grounding
Oil Type: Venezuelan Merey and Pilon Crude

<u>Summary:</u> After the tank vessel *M/V ALVENUS* grounded in the Calcasieu River Bar Channel (LA) on July 30, 1984, the vessel suffered structural failure. Over a period of about six days, 2.7 million gallons of Venezuelan Merey and Pilon crude were discharged into the Gulf of Mexico. A number of problems involving weather, contractors and the magnitude of the spill prevented effective removal of oil from the area around the spill site. One problem in particular was the non-availability of adequate storage of the recovered oil. The slick that formed was very coherent; however, the oil was too viscous for dispersants to be effective, so they were not used. A 75-mile slick from the spill eventually fouled Texas beaches in the vicinity of Galveston. (Alejandro and Buri, 1987).

<u>Applicability of Alternative Burning Techniques:</u> The ALVENUS spill occurred far enough from a populated area such that burning might be considered, particularly with the slick drifting to the West. The location is near the Louisiana offshore oil fields such that a Concept I - III device might be pre-staged in the area. The spill persisted for six days, and the slick was cohesive. Although rough seas were encountered, booms were deployed around the vessel. There is some question on the burnability of the oil. However, it appears that the use of a Concept I -III device might reasonably be considered in such circumstances.

AMAZON VENTURE

Date of Spill: 12/04/86
Location of Spill: Savannah River, GA
Volume of Spill: 11,900 bbl
Cause of Spill: Valve malfunction
Oil Type: No. 6 Fuel Oil (Type 4)

Summary: An oil spill reported to the U.S. Coast Guard on December 4, 1986, turned out to be 500,000 barrels of No. 6 fuel oil discharged over a two-day period by a faulty valve system aboard the *AMAZON VENTURE*, which was docked at the Georgia Port Authority Garden City Terminal on the Savannah River. The spill influenced all 35 kilometers of the tidal portion of the river. Extensive containment and sorbent booms were used to protect the Savannah National Wildlife Refuge and shellfish grounds in Wassaw Sound; however, strong currents and tides made this effort ineffective in both locations. Boom entrainment can occur at current speeds above 0.5 meters per second; current speeds of 6 meters per second were encountered. Boom deployment was also made difficult by the currents. When neap tides gave way to spring tides, the 3-meter tidal range caused additional problems: low water left booms high and dry, and high water caused previously uncontaminated areas to be soiled. Lack of access to recovery sites by heavy equipment limited the use of vacuum trucks and skimmers (Biedenbender and Michel, 1989).

Applicability of Alternative Burning Techniques: Although the spill occurred in a river and marsh environment with shallow water areas, high currents and the unburnable nature of the oil would preclude use of alternative burning techniques (Concepts IV and V).

AMERICAN TRADER

Date of Spill: 02/07/90
Location of Spill: Huntington Beach, CA
Volume of Spill: 9,458 bbl
Cause of Spill: Grounding on anchor
Oil Type: North Slope Crude

Summary: While maneuvering at an offshore mooring, the tank ship *AMERICAN TRADER* punctured its hull when it set down on one of its anchors. The February 7, 1990, spill released about 9,500 barrels of Alaskan North Slope crude offshore from Huntington Beach, California. Containment booms were positioned around the vessel.

> ...[A] fleet of 15 major skimming vessels and 25 support/boom tow vessels were on the scene, working a slick that had grown to more than 40 square miles...Six days of fair weather and mild seas, coupled with the impressive skimming armada, permitted the recovery of 14,100 barrels of emulsified oil and water, which subsequently yielded 2,376 barrels (25.1 percent of the total spilled) of recycled crude. (Card and Meehan,

1991).

Beaches were cleaned by hand, with workers shoveling oil and contaminated sand into bags. Tarballs were raked up and free oil was collected with sorbent pads. Oil snare pompoms were used in shallow water to collect oil before it soiled the beach. Exclusion booming at predetermined deployment points was used to protect wetlands. Berming was used to protect the Santa Ana River after booms proved ineffective due to high currents. Dispersant use was requested but not approved (Card and Meehan, 1991).

Applicability of Alternative Burning Techniques: Because of the rapid release of the oil, the proximity of populated areas, and the success of the mechanical recovery operations, it is unlikely that alternative burning methods would have been considered.

AMOCO CADIZ

Date of Spill: 03/16/78
Location of Spill: Brittany, France
Volume of Spill: 1,619,048 bbl
Cause of Spill: Tanker Grounding
Oil Type: Arabian and Iranian light crude (Type 2), Bunker C (Type 4)

Summary: When the *AMOCO CADIZ* went aground on rocks off France in March of 1978, large areas of the Brittany coast were threatened (and eventually soiled) by the 223,000 tons of light crude oil that was spilled. Initial countermeasures and cleanup were delayed by two weeks due to rough seas and the isolated location. Rapid release of the oil produced a slick 18 miles wide by 80 miles long. Burning was dismissed as an oil removal method because the prevailing winds would have carried smoke (and unburned oil carried by the smoke) inland. Skimmers, which were used in harbors and protected areas, had limited usefulness due to seaweed that fouled pumps and hoses (Bellier and Massart, 1979).

Application of Alternative Burning Techniques: None of the Concepts proposed would have been applicable to this spill.

APEX Barges

Date of Spill: 07/28/90
Location of Spill: Galveston Bay, TX
Volume of Spill: 16,476 bbl
Cause of Spill: Two barges collided with tanker

Oil Type: No. 5 Oil

Summary: On July 28, 1990, the tankship ***SHINOUSSA*** **collided with** ***APEX*** **barges** ***3417*** **and** ***3503*** **in Galveston Bay, Texas.** ***APEX 3417*** **sank, spilling 644,500 gallons of catalytic feedstock oil;** ***APEX 3503*** **was damaged and leaked 47,500 gallons. The two leaking barges were boomed within hours; however, oil was entrained under the booms by the current. Use of sorbents to recover oil inside the booms was insufficient. A deck barge with two vacuum trailer units, skimmers, and skimming barriers were used, as well as a skimmer owned by Exxon:**

> **This skimmer consisted of a small deck barge with about 400 barrels storage capacity in deck tanks and oil-water separation equipment. It had movable rigid booms that could be quickly set out at about a 45-degree angle from each side providing a 120-foot sweep width to deflect oil to an internal sump where the oil was skimmed. Pushed by a small 4 ½-foot draft towboat, it was a very effective and mobile skimmer capable of operating in most of the shallow waters of the bay...It was employed for the duration of the cleanup and eventually recovered 145,000 gallons of oil, nearly half of the total recovered. (Greene, 1991)**

Deflection booms were used along an area of shoreline where heavy concentrations of oil were headed. "They proved very effective in directing the oil into the shore where vacuum trucks could recover it" (Greene, 1991). Bioremediation was approved on a not-to-interfere basis, with requirements for documentation and monitoring.

One major finding from this spill concerned skimmers:

> **Shallow water, less than 6 feet, can cause significant problems. Skimmers and boats that can operate in 2 to 3 feet, or less, are needed to skim oil and deploy booms in shallow estuaries...Lack of adequate numbers of shallow-water (less than 6 ft) skimmers inhibited recovery of oil in the shallow nearshore areas. There were occasions when oil impacted the shore because a suitable skimmer was not available. (Greene, 1991)**

Applicability of Alternative Burning Techniques: **The APEX barge spill highlights the problems encountered in containing and recovering oil in shallow water. Oil was deflected to the shore and collected using vacuum trucks. If the collection areas had been inaccessible to vacuum trucks, alternative burning using the Concept V approach may**

have been effective (inshore burning has been approved in several other Gulf oil spills). The burnability of the No. 5 oil would be questionable.

ARCO ANCHORAGE

Date of Spill: 12/21/85
Location of Spill: Port Angeles, WA
Volume of Spill: 5690 bbl
Cause of Spill: Tank vessel grounding
Oil Type: North Slope Crude

Summary: **When the *ARCO ANCHORAGE* ran aground on December 21, 1985, in Port Angeles Harbor (WA), it spilled 5,690 barrels of Alaska North Slope crude. Booms and skimmers were used in the offshore recovery process. Internal transfer of oil within the tanker halted oil flow within 5 hours of the initial release. The oil circulated within the harbor with tidal currents. Skimmers were able to work 24 hours per day, seven days per week for five weeks. Low winds and the installation of radar aboard the skimmers aided the recovery effort (Levine, 1987). Booms were also used in beach cleaning operations. Beach materials were mechanically agitated by bulldozers with ripper assembly and water jets to release trapped oil; the oil was then contained by booms and recovered using sorbent materials, rope skimmers and a vacuum truck (Miller, 1987).**

Applicability of Alternative Burning Techniques: **The proximity of a populated area and the rapid termination of the release would clearly preclude use of Concepts I through III. There is also no suggestion that Concepts IV or V would be used in the shoreline cleanup.**

Ashland Oil Spill

Date of Spill: 01/02/88
Location of Spill: Monongahela River, West Elizabeth River, PA
Volume of Spill: 23,810 bbl
Cause of Spill: Storage tank structural failure
Oil Type: Diesel Fuel (Type 2)

Summary: **A collapsing oil storage tank at the Ashland Oil Company terminal in Floreffe, Pennsylvania, released approximately 3.9 million gallons of No. 2 diesel fuel. The fuel overtopped the containment berms, flowing into a storm drain and eventually into the**

Monongahela River. The spill occurred on January 2, 1988. After passing over locks and dams on the river, the oil became emulsified and spread throughout the water column. Booms were ineffective in containing the emulsified oil (Laskowski and Voltaggio, 1989). Booms did contain some of the unemulsified product. "Multiple deflection and collection booms, assisted by strategically placed barges used for oil deflection...recovered the largest amounts of fuel" (Miklaucic and Saseen, 1989). Additionally, one lock and dam structure was used to recover significant amounts of product; the upstream end of the lock was left open and the downstream end was closed, forming an enclosure for collecting oil (Miklaucic and Saseen, 1989). In all, 1,905 bbl of oil were recovered. Ice, which was present on the river, contained some oil but made placement of booms and use of sorbent materials difficult (Laskowski and Voltaggio, 1989).

<u>Applicability of Alternative Burning Techniques:</u> In this particular instance, the emulsification and dispersion of the oil, and the presence of ice, would have precluded the use of alternative approaches described in Concepts IV and V. However, the booming and recovery that was undertaken suggests that under open water conditions where the oil remained on the surface, Concept V may be viable in dealing with such large river spills, providing, of course that permission to burn can be obtained.

ATLANTIC EMPRESS

Date of Spill: 07/19/79
Location of Spill: 20 miles northeast of Tobago
Volume of Spill: Unknown, 3.5 million bbl potential
Cause of Spill: Collision with *AEGEAN CAPTAIN*
Oil Type: Crude Oil

Summary: The collision of the *ATLANTIC EMPRESS* and the *AEGEAN CAPTAIN*, two very large crude carriers, on July 19, 1979, in the Caribbean resulted in the loss of 27 lives and the potential for the discharge of 3.5 million barrels of crude oil (the combined cargoes of the two ships). The *AEGEAN CAPTAIN* was towed to Curacao, where it was offloaded. The *ATLANTIC EMPRESS* was taken in tow while burning, and tugs sprayed water on the vessel to cool it. Firefighting efforts succeeded in extinguishing one fire onboard, but an explosion from another fire irreparably damaged the vessel. Oil on the vessel and on the water continued to burn. A large release of oil was followed by an increase in the ship's list, and the last tow line was released. The vessel burned and sank. An oil slick 2 mi wide and 15 mi long resulted from the spill. Much of the oil was consumed by the fire. Plans were made to use dispersants to protect Tobago beaches but were not implemented. The slick was monitored by air and sea and allowed to dissipate naturally (Horn and Neal, 1981).

Applicability of Alternative Burning Techniques: None of the concepts proposed (specifically Concepts I - III) would be applicable to this spill due to rapid dispersion of the oil and non-stationary source.

BRAER

Date of Spill: 01/05/93
Location of Spill: Garths Ness, Shetland Islands
Volume of Spill: 532,400 bbl
Cause of Spill: Tanker grounding
Oil Type: Norwegian Crude

Summary: *BRAER*, a tanker containing 84,700 metric tons of Norwegian Gullfaks crude oil, drifted aground at Garths Ness, Shetland Islands on January 5, 1993, after losing engine power. Oil began to leak immediately and continued for eight days. On the eighth day the vessel broke into three sections and all remaining oil was released.

On day two, full-scale aerial spraying of dispersants from DC-3s was conducted, with a

total of 100 tons of dispersant being used. Strong winds on subsequent days prevented further spraying. A small amount of spraying was done near the wreck on day three using helicopters, but that effort was curtailed by the weather. High wave energy helped in natural dispersion of the oil.

Efforts were made to prevent damage in environmentally sensitive areas:

> **Operations consisted primarily of measures to prevent oil from reaching the most environmentally and economically sensitive areas and some beach cleaning. Booms and barriers were placed across the entrance to two lochs and a rock dam was built between East and West Burra. Absorbent booms were supplied to salmon farms under threat and assistance was provided with their deployment. (Harris, 1995)**

At both of the lochs, booms were damaged by weather. No open water recovery of oil was attempted due to the weather conditions and the propensity for the oil to disperse (Harris, 1995).

Applicability of Alternative Burning Techniques: Weather conditions and the natural dispersion of the oil precluded any surface recovery operations. In view of this, it is unlikely that any of the alternative burning approaches could have been employed.

Brunswick Naval Air Station

Date of Spill: 03/26/93
Location of Spill: Brunswick Naval Air Station, Brunswick, ME
Volume of Spill: 1500 bbl
Cause of Spill: Valve malfunction
Oil Type: JP-5 aviation fuel

Summary: During the period March 26 - 29, approximately 63,500 gallons (1500 bbl) of JP-5 aviation fuel was discharged from a fuel tank farm at the Brunswick Naval Air Station. The fuel entered a storm sewer system and migrated into a fresh water wetland where it was contained by ice, snow and other natural barriers. The spill was discovered on March 29. Conventional oil recovery technologies were employed at the outset but discontinued due to difficulty in accessing the site, and the potential for damage to the wetland. A large scale burn was conducted on April 6, at which time the entire surface area of the wetland that had been oiled was allowed to burn. Two burns followed on April 7-8,

removing remaining pockets of oil not removed in the initial operation. It was estimated by the Maine Department of Environmental Protection, that less than 450 gallons (roughly 10 bbl) remained in the wetland at the conclusion of the burn. (Eufemia, 1994)

Applicability of Alternative Burning Techniques: The Brunswick spill is noteworthy as it highlights the difficulties in recovering oil in sensitive marshlands, and the utility of burning as a countermeasure under these conditions. Inshore burning is becoming more accepted as a viable option under these circumstances. If the oil had not been contained in the marsh, but flushed out into shallow water, the use of Concepts IV and V might well prove viable.

BUFFALO 292

Date of Spill: 03/18/96
Location of Spill: Houston Ship Channel, TX
Volume of Spill: 3,000 bbl
Cause of Spill: Barge structural failure
Oil Type: IFO 380

Summary: While transiting in the Houston Ship Channel, the barge *BUFFALO 292* spilled approximately 3,000 barrels of IFO 380 when it suffered structural damage. The spill occurred on March 18, 1996, during spring break, which is a popular tourist time on Gulf beaches. Although some oil went ashore inside the Galveston Bay entrance, most of the oil escaped into the Gulf of Mexico, where it traveled south and then east toward Corpus Christi (Lehr *et al.*, 1997).

In the area of the barge, protective booming and lightering were used. Five offshore skimmers and six shallow water skimmers, as well as 34,000 feet of containment boom and more than 150,000 feet of sorbent boom and viscous sweep were used in the cleanup. Weathered oil began to cause problems for nearshore skimming operations on day three, and on day six, nearshore skimming operations were halted. Offshore skimming operations were able to continue longer, but eventually their effectiveness also decreased. Conventional skimmers were not able to collect the oil once it had weathered, due to the formation of tar mats and patties up to 15 feet in diameter, some of which were partly submerged. A weir skimming system became fouled when trying to skim the tar mats. By day nine, offshore skimming effectiveness had decreased to a point where the resources were to be released. "However, daily overflights continued to track widely distributed streaks of tar mats, tar balls and patties, which, if not recovered in the offshore zone, would impact the beaches to the south..." (Clark *et al.*, 1997).

An experiment was conducted to determine whether vessels of opportunity could be used to collect the remaining weathered oil. Two shrimp boats towed a shrimp net between them,

collecting the patties and mats in the net. The success of this experiment led to the use of six shrimp boats that operated in pairs, using modified nets with 200 feet of containment boom on each strung between the boats. Pompom snares were tied to the nets. "On the first day of operations one pair of vessels was able to recover approximately 30 barrels of product on the first pull" (Clark *et al*., 1997). Rough seas caused seasickness problems among contractor cleanup crews on the shrimp boats. After the work was finished and the shrimp boats released, the boats had to be decontaminated and the nets were disposed of.

<u>Applicability of Alternative Burning Techniques:</u> The heavy consistency of the oil precluded conventional mechanical recovery operations. In view of this, it is unlikely that alternative burning techniques would be attempted.

BURMAH AGATE

Date of Spill: 11/01/79 to 01/08/80
Location of Spill: Galveston Harbor
Volume of Spill: 254,761 bbl
Cause of Spill: Tanker collision
Oil Type: Nigerian Crude, blended crude (high naptha content)

<u>Summary:</u> A collision between the tanker *BURMAH AGATE* and the freighter *MIMOSA* on November 1, 1979, resulted in the loss of 33 lives, with the tanker coming to rest on the bottom. Ruptured tanks caused an explosion and fire that burned out of control for over two months. Although oil continued to leak from the tanker, much of it was consumed by the fire on the vessel. Oil containment efforts included the use of booms, skimming barrier systems and mobile skimmers near the leaking tanker (Kana *et al.*, 1981), but efforts were complicated by the fire (boom caught fire) and the shifting position of the slick. Equipment was also used to protect sensitive tidal inlets and marshes, although the amount of oil impacting these resources was limited.

<u>Application of Alternative Burning Techniques:</u> Although the BURMA AGATE offered a steady source of oil for extended duration, most of it was consumed by the fire. Stationary skimming operations proved difficult. Because of close proximity to Galveston, if the vessel had not caught fire, mechanical recovery would have been primary countermeasure. None of the alternative concepts appears applicable.

Chevron Main Pass Block 41

Date of Spill: 02/10/70
Location of Spill: 11 miles east of Mississippi River Delta, LA
Volume of Spill: 65,000 bbl
Cause of Spill: Well Blowout
Oil Type: Louisiana Crude

Summary: Soon after the spill, Chevron began cooling the platform with water, making preparations to cap the well, and assembling cleanup equipment to contain and recover oil once the fire was extinguished. By February 27, a 10 yd wide by 10 mile long slick was observed extending from the platform. The fire was put out on March 10, but oil continued flowing at a rate of 1000 bbl/day until March 30 (48 days later) when the well was finally capped. A boom constructed of barges contained much of the oil at the well (estimated at 85%-90%). A dozen skimmers of various types were in operation by March 11, and between March 9 and March 19 a total of 15,613 bbl of oil and emulsion was recovered. Heavy weather hampered recovery operations between March 17 -19.

Application of Alternative Burning Techniques: Main Pass 41 represents an ideal scenario for use of Concepts I - III. The spill involved a steady source of 1000 bbl/day (well within the design capacity of Concepts I through III), a well-defined slick, burnable oil, and a location far enough offshore to warrant burning approval, yet close enough to a staging site to allow the device to arrive on-scene early in the spill.

Colonial Pipeline Enoree River

Date of Spill: 12/20/91
Location of Spill: Fountain Inn, South Carolina
Volume of Spill: 13,000 bbl
Cause of Spill: Pipeline leak
Oil Type: No. 2 Fuel Oil

Summary: A leak in the Colonial Pipeline Company pipe near Fountain Inn, South Carolina, during December 1991 resulted in the release of 13,000 barrels of No. 2 fuel oil. The pipeline, which extends from Texas to New Jersey, was leaking at a location near Durbin Creek, where the pipeline is eight to twelve feet below the creek bed. Durbin Creek flows into the Enoree River, which supplies water for the towns of Clinton and Whitmire, approximately 30 and 50 miles downstream from the location of the leak.

A mill pond located approximately 17 miles downstream from the leak was chosen for containment booming. The boom successfully contained oil, but removal was slow due to the lack of pumping and transfer equipment. The containment capacity of the booms

was being exceeded. The creek at the leak site had been diverted so that oil leaking from the pipeline could be recovered. Permission was sought to use Elastol, an oil herding/collection agent, but it was denied. Of the estimated 13,100 barrels of oil spilled, approximately 12,600 barrels were recovered (Smith, 1993).

<u>Applicability of Alternative Burning Techniques:</u> Because of the effectiveness of mechanical recovery at the mill pond location, it is not likely that alternative burning measures (such as Concept V) would have been considered.

Ekofisk Bravo

Date of Spill: 04/22/77
Location of Spill: North Sea off Norway
Volume of Spill: 202,380
Cause of Spill: Well blowout
Oil Type: Ekofisk Crude

<u>Summary:</u> Well B-14 on the Phillips Petroleum "Bravo" platform experienced a n oil and gas blowout in 230 ft of water, creating a continuous discharge from an open pipe 60 ft above the water surface. The spill rate was 28,080 bbl/day continuing until the well was capped seven days later on April 30. Because of the sea conditions and distance from shore, the oil was dispersed by wind and wave action; no shorelines were oiled. No countermeasures were attempted.

<u>Applicability of Alternative Burning Techniques:</u> The Ekofisk spill fits the design scenario for Concepts I through III, although the processing capacity of all three devices would be exceeded. However, if the device could be deployed in a timely manner, a significant amount of oil could be disposed of. The device would have to be located far enough from the platform to ensure that the escaping gas was not ignited.

ESSO BAYWAY

Date of Spill: 01/28/79
Location of Spill: Port Arthur, Texas
Volume of Spill: 6,500 bbl
Cause of Spill: Tanker grounding
Oil Type: Light Arabian crude, Type 2

Summary: A puncture in the number two center cargo tank of the *ESSO BAYWAY* on January 28, 1979, resulted in the spill of 6,500 barrels of Light Arabian crude oil into the Neches River near Port Arthur, Texas. River flow and tidal action moved the oil up and down the river. Booms were used to prevent the oil from proceeding downstream to environmentally fragile areas, and vacuum trucks and equipment were used to collect oil. Marsh cleanup was conducted with hand tools and sorbent pads and booms. Grass along the bayou was flushed so that the freed oil could be collected by vacuum trucks (Meyers, 1981).

Applicability of Alternative Burning Techniques: Based on the available information, it appears that Concepts IV and V could have been employed at points along Neches River, assuming that approval for limited inland burning operations could be obtained.

Exxon Bayway Refinery

Date of Spill: 01/02/90
Location of Spill: Arthur Kill, NY
Volume of Spill: 13,500 bbl
Cause of Spill: Pipeline Leak
Oil Type: No.2 Heating Oil

Summary: An Exxon underwater pipeline leaked 13,500 barrels of No. 2 heating oil into the waters of Arthur Kill (between Staten Island, NY, and NJ) on January 2, 1990. Containment booms were used

> ...to protect sensitive areas and take advantage of natural collection areas. Additional boom was deployed to contain identified pockets of oil...Self-propelled oil skimmers were utilized in areas where heavy concentrations of free-floating oil and mousse existed on the open water...The [Clean Harbors Cooperative] skimmers were supplemented by two Marco skimmers and one JBF skimmer from the U.S. Navy. Vacuum trucks were used around the clock to remove oil at containment sites where shore-side accessibility permitted. (Bubar and Czarnecki, 1991).

The ongoing response effort lasted for about two months, with oil being removed from sediments as it was found. Custombien, a bioremediation enhancing fertilizer, was applied in June.

<u>Applicability of Alternative Burning Techniques:</u> The rapid spreading of the oil and the proximity of the spill to a populated metropolitan area would undoubtedly rule out the use of alternative burning approaches.

Exxon Pipeline Company, Compano Bay

Date of Spill: 01/07/92
Location of Spill: Compano Bay, Texas
Volume of Spill: 2950 bbl
Cause of Spill: Pipeline rupture
Oil Type: South Texas Light Crude

<u>Summary:</u> On January 7, 1992, a rupture occurred in the Exxon Pipeline Company pipeline during transfer of crude oil from their Harbor Island facility to their facility in Vanderbilt, TX. The discharged occurred in a privately owned tidal mud flat at the mouths of Chiltipin Creek and the Aransas River near Compano Bay. Maintenance and cleanup crews were dispatched to the scene on January 8, to secure the line and commence cleanup. Containment boom was deployed in the Aransas River, and sorbent boom placed at the leading edge of the spill which was still 1500 ft. from the edge of the water. Conventional cleanup techniques at the site such as skimmers, pumps, and sorbents proved to be inadequate, and some were ruled out completely due to potential damage to the marsh. In-situ burning was identified as a viable alternative. On the third day of the spill, a successful test burn was conducted. On January 11, a full-scale burn was initiated which lasted for 25 hours. Visual inspections (both aerial and on the ground) indicated that 80 to 85% of the 1700 bbl of oil actually entering the marsh had been removed.

<u>Applicability of Alternative Burning Techniques:</u> The Compano Bay spill is noteworthy as it once again highlights the difficulties in recovering oil in sensitive marshlands, and the utility of burning as a countermeasure under these conditions. If the oil had not been contained in the marsh, but had entered shallow water areas of Compano Bay, the use of Concepts IV and V might well prove viable.

EXXON VALDEZ

Date of Spill: 03/24/89
Location of Spill: Prince William Sound, AK
Volume of Spill: 262,000 bbl
Cause of Spill: Tanker Grounding
Oil Type: Prudhoe Bay Crude

Summary: **The EXXON VALDEZ spill was the largest and most environmentally damaging spill in U.S. history, ultimately impacting 1,100 miles of U.S. coastline. At the height of the response, more than 11,000 personnel and 1,400 vessels were involved in the cleanup.**

The initial release was rapid; within six hours of the grounding essentially all of the 262,000 bbl of oil had entered the waters of Prince William Sound. Fortunately the remaining 1 million bbl of cargo was successfully offloaded once the vessel was stabilized. By March 30, the oil extended 90 miles from the spill site.

Countermeasures and cleanup operations were initiated immediately aided by the close proximity of the Valdez support base. Dispersants were tested but did not prove particularly effective. A successful in-situ burning test was conducted on March 26 using fire-resistant boom which resulted in removal of 350 bbl of oil in roughly an hour. However, before further burning operations could be mounted, a storm intervened on the evening of March 26 with 70 mph winds which emulsified the oil and drove much of it ashore. From this point on, mechanical recovery on the water and mechanical removal ashore were the primary cleanup techniques. The shoreline cleanup effort extended over the next two years.

Applicability of Alternative Burning Techniques: **The EXXON VALDEZ spill was truly a catastrophic spill due to the large amount of oil and the environmental sensitivity of the surrounding area. Because of the almost instantaneous release of the oil, rapid dispersion of the slick, and emulsification of the oil, the use of alternative burning approaches would not have had a measurable impact on the success of the cleanup.**

Hasbah 6

Date of Spill: 10/02/80 to 10/10/80
Location of Spill: Gulf of Arabia (250 kn NW of Qatar, 140 km N of Saudi Arabia)
Volume of Spill: 100,000 bbl
Cause of Spill: Well Blowout
Oil Type: Iranian Crude (Type 4)

Summary: **Exploratory well drilling in the Arabian Gulf near Saudi Arabia resulted in the Hasbah 6 well blowout on October 2, 1980. Hydrogen sulfide gas released from the well hampered operations, and heavy crude oil flowed from the well for eight days before the well could be capped. Skimming operations were performed in areas where the oil threatened land areas, rather than in areas where oil concentrations were greatest (Ryan,**

1983). Dispersants were also applied to the slick. Nearshore booms were deployed to protect recreational facilities and desalinization plants.

<u>Applicability of Alternative Burning Techniques:</u> Because of the extended duration of the release (8 days), and the safe distance from population centers, Concepts I and III could possibly be used assuming that oil would remain burnable upon reaching the surface. Such a blowout is the specific scenario envisioned for Concepts I and III. For Concepts I and II it is assumed that the device is located within the region (within 250-500 miles of the spill site).

Ixtoc I

Date of Spill: 06/03/79 to 03/23/80
Location of Spill: Bahia de Campeche, Mexico
Volume of Spill: 3,522,400 bbl
Cause of Spill: Offshore platform blowout
Oil Type: Crude oil (Type 3)

<u>Summary:</u> Blowout of the exploratory well Ixtoc I in the Bay of Campeche in the Gulf of Mexico (June 3, 1979) led to the world's largest oil spill up to that time (O'Brien, 1981). The spill provide a steady source of oil (10,000 - 30,000 BPD) until the well was finally capped on March 23, 1980 (almost ten months after the spill). The oil was burnable and ignited and burned on the water at the wellhead. PEMEX claimed that half of the oil released was burned at the wellhead. The National Strike Force used the USCG skimming barrier system to contain and collect spilled oil, deploying it in a stationary mode for long periods of time.

<u>Application of Alternative Burning Techniques</u>: Ixtoc I would be an ideal venue for application of Concepts I through III. The long duration of the spill would allow transport of all three concepts to the scene. Oil was available at 10,000 BPD for 10 months, and the oil was burnable near the wellhead. Weather conditions were generally moderate. The spill was accessible to PEMEX shore facilities which supported the relief well and capping effort.

KIRKI

Date of Spill: 07/21/91
Location of Spill: Cervantes, Western Australia

Volume of Spill: 135,000 bbl
Cause of Spill: Tanker structural failure, fire
Oil Type: Light Murban Crude (Type 2)

Summary: On July 21, 1991, while approaching the Western Australian coast, the tanker *KIRKI* lost its bow section, which resulted in a fire at the site of the break. The tanker was carrying 82,660 tons of Murban light crude oil and 1,800 tons of fuel, diesel oil and lubricants (Brodie, 1993). The separation resulted in the spill of an estimated 8,700 metric tons of cargo in the first day of the spill. The crew was successfully rescued and the vessel was taken in tow with some difficulty by a salvage charter vessel. While under tow in heavy weather, the forward bulkhead was damaged further and began to leak cargo. Cargo transfers were made between the tanker's tanks to minimize the loss. Further structural damage to the vessel caused the removal of some salvage personnel, while those remaining tried to improve trim by moving cargo. On August 13, the *KIRKI* was in a location and position to attempt transferring cargo to another vessel. The next day, transfer to *FLYING CLIPPER* began and was concluded on August 19.

> **The quantity transferred included 64,372 metric tons of cargo and 1,290 tons of bunkers; 600 tons of cargo was left on board as unpumpable. Of the total cargo, approximately 17,700 tons was lost to the sea, an estimated 6,500 on July 21 and 11,200 during the tow northwards. (Brodie, 1993)**

In the initial spill area, fishing vessels were outfitted with breaker boards and tasked with running through thick patches of oil near the shore to disperse the slick mechanically. Aircraft sprayed dispersants on the oil near the vessel (Brodie, 1993). The use of booms and skimmers was precluded by heavy seas. Much of the oil had evaporated or dispersed naturally within three days of the spill.

Applicability of Alternative Burning Techniques: Because of the rapid release of the oil, and heavy seas which prevented surface recovery operations, it is unlikely that any of the alternative burning measures could have been employed.

KURDISTAN

Date of Spill: 03/15/79
Location of Spill: Cabot Strait, Newfoundland
Volume of Spill: 43,900 bbl
Cause of Spill: Tanker structural failure
Oil Type: Bunker C (Type 4)

Summary: The breakup of the British tanker *KURDISTAN* in Cabot Strait on March 15, 1979, resulted in the spill of 7,000 tons of bunker C oil, and the potential for the further release of 23,000 tons of oil from the two sections of the ship that remained floating. The spilled oil was difficult to locate and track, due to its tendency to float below the surface. Oil trapped at the ice edge was collected using a barge equipped with backhoes, booms and sorbent material; however, the aerial extent of the oil at that point was too large for effective use of this method. Oil was collected as it came ashore (Duerden and Swiss, 1981).

Application of Alternative Burning Techniques: Because of the rapid release of the oil, its sinking below the surface, and the difficulty in burning Bunker C, none of the alternative concepts would have been viable.

MEGA BORG

Date of Spill: 06/08/90
Location of Spill: Gulf of Mexico, 57 miles SW of Galveston, TX
Volume of Spill: 100,000 bbl
Cause of Spill: Tanker explosion
Oil Type: Angolan Palanca Crude (Type 2)

Summary: On June 8, 1990, while transferring Angolan Palanca crude during lightering operations off the Texas coast in the Gulf of Mexico, the tankship *MEGA BORG* suffered an explosion and fire, causing loss of life. The receiving tankship, the *FRAQMURA*, initiated an emergency breakaway procedure, during which 10,000 gallons of oil spilled. Initial efforts centered on extinguishing the fire, which took one week. After the fires were out and inert gas was pumped into the tanks, the remaining cargo was lightered. In all, 3.9 million gallons of oil were missing, including oil consumed in the fire (Leveille, 1991).

Simultaneously, authorization was obtained to use dispersants, and application began on June 10. The next day, skimmers began recovering oil.

> **At the peak of the cleanup offshore more than 30 commercial vessels and two Coast Guard cutters were involved. These vessels were working 12 skimmers and two USCG skimming barriers, assisted by the *Ecopemex* [Mexican government's skimming ship], which skimmed over 100,000 gallons of oil and mousse...Massive air support to the skimming operation was required...skimmers without continuous air support are far less**

> **effective, due to their limited height of eye and inability to spot the oil. This becomes even more true near the end of a response, when the recoverable oil is spread out over a fairly large area. (Leveille, 1991)**

Recovery operations collected 547,000 gallons of oil and mousse (Leveille, 1991). In addition, 11,300 gallons of dispersant were applied to the slick. It is estimated that much of the oil was removed by evaporation (as much as 50%) or burned.

Applicability of Alternative Burning Techniques: The MEGA BORG spill is interesting in that it resulted in a steady release of burnable oil over a period of several days. In this particular spill, much of the oil was burned by the fire on the tanker. If the fire had not persisted, the steady source and offshore location of the spill may have presented the opportunity to deploy a device such as Concepts I - III. Concept III may have been particularly effective due to its air-transportability and ease of deployment.

MORRIS J. BERMAN

Date of Spill: 01/07/94
Location of Spill: Punta Escambron, San Juan, PR
Volume of Spill: 19,000 bbl
Cause of Spill: Tank barge grounding
Oil Type: No. 6 fuel oil

Summary: On January 7, 1994, the MORRIS J. BERMAN ran aground on a nearshore reef 200 yds off of Punta Escambron in San Juan Puerto Rico. Oil continued to leak for a week following the grounding causing continued contamination of the adjacent shallow lagoons and shoreline. To alleviate the ongoing pollution, on January 15, the barge was refloated, towed to a scuttling site 20 miles offshore, and sunk.

Immediate countermeasures and cleanup offshore consisted of lightering the barge, and conducting skimming operations using an MSRC response vessel offshore. These measures resulted in the removal of 17,000 barrels of oil from the water and leaking barge. Most of the remaining cleanup effort involved shoreline cleaning using mechanical removal techniques, and some chemical washing.

Applicability of Alternative Burning Techniques: The type of oil involved (No.6) and the proximity of the spill to populated areas would probably preclude the use of any of the alternative burning approaches investigated.

NESTUCCA

Date of Spill: 12/23/88
Location of Spill: Grays Harbor, WA
Volume of Spill: 5,500 bbl
Cause of Spill: Collision with tug
Oil Type: Bunker C (Type 4)

Summary: **On December 22, 1988, while towing the barge *NESTUCCA* into Grays Harbor, Washington, the tug *OCEAN SERVICE* broke its tow line. In attempting to regain the tow line, the tug punctured the barge, which contained over 70,000 barrels of Bunker C oil. Rather than attempting an entrance to Grays Harbor with poor weather and the tug's rudder damaged, the tug headed out to sea. The spilled oil affected most of the Pacific coast of the state of Washington, and the Canadian shoreline on the southern part of British Columbia - Vancouver Island. No containment or mechanical recovery was attempted at sea due to the rough seas (6-10 ft swells) and the fact that the oil floated below the surface such that it was undetected until coming ashore. Cleanup efforts involved beach and bird cleaning. Oiled driftwood was disposed of by burning, and high speed power fans were used to increase the efficiency of the burn (Yaroch, 1991).**

Applicability of Alternative Burning Techniques: **The behavior of the oil and sea conditions, and the nature of the Washington - British Columbia Coast would precluded use of the alternative burning techniques. It is also questionable whether the untreated oil could be ignited. It is notable that burning was conducted on the beaches indicating that the use of alternative approaches to burning might well be approved in the region under different scenarios.**

NORD PACIFIC

Date of Spill: 07/13/88
Location of Spill: Corpus Christi, TX
Volume of Spill: 15,350 bbl
Cause of Spill: Tanker collision with dock
Oil Type: North Sea Crude (Type 2)

Summary: **While docking in the inner harbor at Corpus Christi, Texas, on July 13, 1988,**

the *NORD PACIFIC* suffered an eight-foot gash in one of its tanks. The damage resulted in a spill of 15,350 barrels of North Sea crude over a one-hour period. Containment booms were placed around the vessel and in areas where free-floating oil could be directed toward collection areas for removal by vacuum trucks. Approximately 74 percent of the spilled oil was estimated as having been recovered in the period from July 13 to July 22. As much as 25 percent of the crude may have evaporated (Alejandro and Crickard, 1989). Oiled debris was recovered and oil removed from two marsh areas.

<u>Applicability of Alternative Burning Techniques:</u> This spill was not a candidate for alternative burning techniques as it occurred in a populated area, the release of oil was rapid, and mechanical recovery was highly effective in removing the oil.

Norwuz Oil Field

Date of Spill: 02/10/83
Location of Spill: Persian Gulf off Iran
Volume of Spill: 1,904,762 bbl
Cause of Spill: Tanker collision with platform
Oil Type: Norwuz Crude

<u>Summary</u>: On February 10, a tanker colliding with a Norwuz platform caused the riser to collapse into the wellhead causing a 1500 bbl/day release that lasted for 8 months. In March, Iraqi planes attacked the platform igniting the oil. Because the platform was in the middle of a war zone no immediate attempt was made to cap the well. Also in March, another nearby platform was attacked resulting in a 5000 bbl/day spill that persisted for 2 years. By mid-May 1983 it is estimated that between 4000 and 10,000 bbl/day of oil leaked into the Persian Gulf due to the collision and platform damage related to the war.

<u>Applicability of Alternative Burning Techniques:</u> The Iran-Iraq War precluded any countermeasures and cleanup activities. However, under normal circumstances either platform spill would possibly have provided an opportunity for using Concept I - III devices. The 1500 bbl/day spill could be processed using Concepts I, II, or III; the 5000 bbl/day spill would require Concept I or II. This assumes that a Concept I or II device was pre-staged in the Persian Gulf.

PAC BARONESS

Date of Spill: 09/21/87
Location of Spill: 12 miles SW of Point Conception, CA

Volume of Spill: 9,200 bbl
Cause of Spill: Collision with freighter
Oil Type: Bunker fuel and lube oil

<u>Summary</u>: On September 21, 1987, the *PAC BARONESS* (a dry bulk carrier) was damaged in a collision with the freighter *ATLANTIC WING.* As the *PAC BARONESS* took on water, it developed a list to starboard and its stern was underwater. After the crew abandoned ship, the vessel began to drift toward an oil and gas rig. While being towed out to sea, the *PAC BARONESS* sank. Bunker oil bubbled to the surface for several days from the vessel; by Sept. 25 cleanup operations were suspended due to lack of recoverable oil. Estimates place the quantity released at several thousand barrels. Containment boom could not be used at the site due to the water depth. Mechanical recovery and dispersants were used. Approximately 350 bbl of oil were recovered. Clean Seas identified "the need to develop multiple vessel response techniques (such as using containment boom on one vessel to direct oil to the advancing skimmer system on another vessel)" (Onstad and McCloskey, 1989).

<u>Applicability of Alternative Burning Techniques:</u> Because of the limited duration of the release, rapid breakup of the slick, and type of oil, it is unlikely that use of alternative burning techniques (Concepts I - II) would have been considered for such a spill.

PRESIDENTE RIVERA

Date of Spill: 06/24/89
Location of Spill: Delaware River, South of MARCUS Hook, PA
Volume of Spill: 7,310 bbl
Cause of Spill: Tanker Grounding
Oil Type: No. 6 Fuel Oil

<u>Summary:</u> The grounding of the *PRESIDENTE RIVERA* in the Delaware River on June 24, 1989, caused a spill of over 300,000 gallons of No. 6 oil. Eighteen-inch harbor booms were used for containment around the tanker, but currents caused the oil, which formed "tarlike globs" to pass under the boom (Wiltshire and Corcoran, 1991). The thickness of the oil rendered conventional cleanup equipment such as vacuum trucks, sorbent pads, booms and skimming weirs ineffective. The Coast Guard Atlantic Area Strike Team brought its Open Water Oil Containment and Recovery System (OWOCRS), a 48-inch boom designed for high-seas use. Towed by two tugs, the boom collected 40,000 gallons of oil and debris on its first day of operation. Because vacuums were ineffective due to the thickness of the oil, a dredge with a clamshell bucket was used to transfer the oil from the boom to a barge.

Other methods used included a skimmer with a submersion belt system that forces oil and water below the water's surface and collects the oil in a collection bay at the end of the belt. Due to the thickness of the oil, it could not be pumped from the collection bay to the holding tanks, so oil storage was severely restricted. Other booms used were a 36-inch Goodyear inflatable boom, which was unable to hold oil under the conditions encountered, and a 36-inch Sea Curtain boom which captured oil but did not retain it. Boats towing nets captured oil, but the oil could not be emptied, causing loss of the net. This method was abandoned. In shallow areas, obstacles such as buoys caused maneuvering that resulted in loss of oil from the towed booms (Wiltshire and Corcoran, 1991).

Applicability of Alternative Burning Techniques: The thick consistency of the heavy fuel oil precluded mechanical recovery. It can be assumed that the oil was not burnable.

PUERTO RICAN

Date of Spill: 10/31/84
Location of Spill: San Francisco Bay, CA
Volume of Spill: 38,500 bbl
Cause of Spill: Tanker explosion, subsequent breakup during towing
Oil Type: Lube Oil and Bunker C

Summary: On November 3, 1984, explosions caused a fire aboard the tank vessel *PUERTO RICAN* that had departed from San Francisco Bay. The vessel was towed seaward in an attempt to lessen the damage should the vessel begin leaking its cargo. After the fires were extinguished, the vessel was beset by a storm. The following day, the *PUERTO RICAN* broke apart, spilling 30,000 to 34,000 barrels of oil. Weather conditions prevented a planned oil-skimming operation. Dispersant use was approved by the EPA and the California Department of Fish and Game, and the dispersant Corexit 9527 was applied to the spill (Zawadzki *et al.*, 1987).

Applicability of Alternative Burning Techniques: The subsequent breakup during towing resulted in a rapid release of oil in 8-12 foot seas. No offshore countermeasures were attempted except for dispersant application by aircraft. None of the alternative burning devices (Concepts I-III) could have been used under these conditions.

Santa Barbara Well Blowout

Date of Spill: 01/28/69
Location of Spill: 5.5 miles SE of Santa Barbara, CA

Volume of Spill: 100,000 bbl
Cause of Spill: Well blowout
Oil Type: California crude

Summary: On January 28, Union Oil Company Well “A21" experienced a blowout during change of drill bits. The well was capped on February 7, but oil continued to vent through natural faults until December 1969 such that a total of 100,000 bbl of crude oil was released into the Santa Barbara Channel. In the first few days of the spill, the release rate was estimated at 5,000 bbl/day. By March 3, the seepage around the vents had diminished to 30 bbl/day. Dispersants were applied to the spill, but no offshore recovery was attempted (the spill preceded the development of offshore booms and skimmers). Mechanical oil removal on the beaches lasted for 45 days.

Applicability of Alternative Burning Techniques: During the first 10 days of the spill, before the well was capped, use of a Concept I - III device would appear feasible. There is some question as to the burnability of the heavier California crude, particularly if emulsified.

Santa Clara River/Northridge Earthquake

Date of Spill: 01/17/94
Location of Spill: Santa Clara River, Ventura, CA
Volume of Spill: 4,600 bbl
Cause of Spill: Pipeline rupture caused by earthquake
Oil Type: Blended Crude Oil

Summary: A pipeline rupture resulting from the Northridge earthquake in southern California on January 17, 1994, caused more than 4,600 barrels of San Joaquin blended crude oil to spill onto the ground. From there it flowed into a storm drain and a drainage ditch leading to the Santa Clara River. The Santa Clara flows into the Pacific Ocean near Ventura, California, 35 miles away. Initial efforts included a berm at the drainage ditch and underflow dams downstream. During the first two days, vacuum trucks recovered 1,600 barrels of spilled oil trapped by the berm. Deflection booms were used at the dams, and vacuum trucks and drum skimmers were used to collect the oil. At the point where the river disappears underground, a dike was constructed creating a pond where oil could be collected, preventing it from traveling downstream. With the oil contained within this section of the river, the attention turned to collecting as much of the free oil as possible before a predicted rainstorm, which could substantially increase the river flow (Leveille *et al.*, 1995).

Much of the free oil was found trapped in a watercress type of vegetation. The vegetation

was cut and allowed to float downstream to a "logistically practical" collection point, where a debris fence was installed. Problems with this approach included the need to refloat vegetation that stranded prior to the collection point and vegetation that passed through the debris fence at the collection point and had to be collected downstream. One benefit was that the vegetation acted as a sorbent, removing oil from the water as it was collected (Leveille *et al.*, 1995).

Equipment was a problem:

> **Most of the response equipment used was primarily intended for the open ocean and harbors. Boom was invariably too large for the intended application. In most cases it was all we had, so we used it anyway; however, often it was in fact useless and efforts should not have been expended on its use. The wrong boom is the same as no boom - be it too large for a shallow stream or too small for the open water.(Leveille *et al*., 1995)**

Applicability of Alternative Burning Techniques: This spill once again highlights the problems of using equipment designed for offshore and harbor applications in shallow water, restricted areas. However, it is not clear that either of the shallow water alternative burning approaches (Concepts IV and V) could have been employed.

SEA EMPRESS

Date of Spill: 02/15/96
Location of Spill: Milford Haven
Volume of Spill: 45,483 bbl
Cause of Spill: Tanker Grounding
Oil Type: Forties Blend Crude

Summary: On February 15, 1996, the tanker *SEA EMPRESS* ran aground at Milford Haven, United Kingdom, spilling a large quantity of Forties Blend crude oil. Four tugs awaiting the vessel's arrival proceeded to the grounding site and provided aid. The tanker lost steerage in the grounding; the tugs freed the severely damaged vessel about an hour later. Due to an increase in draft, the tanker was not able to proceed either into the harbor or out to sea. It was stuck in the channel, where it anchored. Foul weather caused the tanker to go onto the rocks, despite the efforts of three large salvage tugs. More oil was released. The tanker repeatedly grounded and released oil at low water for the next two days. Finally, the vessel was refloated and towed to a jetty where the remaining cargo was removed. The total oil lost was 72,000 tons of cargo and 360 tons of heavy fuel oil (Harris,

1997).

Dispersant was sprayed in areas at least one kilometer from the coast, in keeping with an agreement not to spray in waters less than 20 meters deep. Since the grounding was within the one kilometer limit, it was necessary to wait for the oil to move away from the shore. During that time the oil emulsified, so spraying was not very effective. Use of demulsifier and dispersant also appeared ineffective. During the following days, spraying was used effectively on fresh oil; as fresh oil leaked during the multiple groundings, spraying was continued. Spraying ceased when oil concentrations were not large enough to warrant spraying and when it was decided that the oil was too weathered and emulsified (Harris, 1997).

Sensitive areas were protected by booms, and the vessel was surrounded by booms at the jetty where the remaining cargo was offloaded; however, oil spilled at the jetty before the boom was in place. Also, strong currents reduced the effectiveness of the booms used at the jetty. Two local oil recovery vessels began work inside the haven; two vessels were fitted with recovery systems and chartered to join the cleanup. Two French oil recovery vessels also participated. Closer to shore, skimmers and an Egmopol barge (a belt skimmer with a capacity of 15 cubic meters) collected oil (Harris, 1997).

Skimmers were also used in areas outside the Haven but within the one-kilometer limit. In locations that were too shallow for the large skimmers, local fishing boats were chartered to collect oil in booms and drag it to deeper waters where it could be recovered by the larger skimmers (Harris, 1997).

<u>Applicability of Alternative Burning Techniques:</u> Because of the rapid release and dispersion of the oil, and the focus on mechanical recovery and dispersants, it is not clear that alternative burning methods would ever be considered.

Shell Oil at Martinez, California

Date of Spill: 04/23/88
Location of Spill: Carquinez Straits, Martinez, CA
Volume of Spill: 9,400 bbl
Cause of Spill: Facility leak
Oil Type: San Joaquin Valley Crude Oil (Type 4)

<u>Summary:</u> On April 23, 1988, the Shell Oil Company Martinez (CA) Manufacturing Complex experienced a leak of 9,400 barrels of San Joaquin Valley crude oil. The oil spilled into a freshwater marsh and continued on to Suisun Bay and Carquinez Strait. Underflow dams were used to prevent additional oil contained in the marsh from reaching Suisun Bay and Carquinez Strait. Booms (both conventional, skirted booms and sorbent booms) were used "to contain, exclude, or divert the spilled oil at a variety of locations"

(Fraser, *et al*., 1989). Shoreline barrier was also employed successfully.

> **Use of the conventional booms was satisfactory in many locations, although the entrances to tidal sloughs presented a major problem owing to the relatively high water currents and to changes in water elevation with the tides, which left the boom suspended above the water surface. The shoreline barrier was especially useful in such installations owing to its ability to confirm to the shoreline and maintain contact with the water surface. (Fraser, *et al*., 1989)**

Sorbent belt-type skimmers, vacuum trucks and sorbents were used to recover oil. Sorbent pompoms were more effective than conventional sorbent pads. Skimmers (weir skimmers and Marco Class I, III, and V skimmers) were used in open waters. In marsh areas too small for skimmers, filter fences were constructed, and sorbent pompoms attached to the fence were changed each day at low tide (Fraser, *et al*., 1989).

Applicability of Alternative Burning Techniques: This marsh/river spill represents a scenario where Concepts IV and V might be effectively employed if tidal currents are moderate. Deployment feasibility would be determined by the specific characteristics at the site in the marsh and river. Concept IV would overcome the loss of boom contact with the water surface; Concept V would prevent boom grounding. Burning would require agency approval. To be effective, cleanup crews would have to adapt to the terrain and work with the tides.

Shell Oil Platform 26

Date of Spill: 12/01/70
Location of Spill: Gulf of Mexico, LA
Volume of Spill: ~ 100,000 bbl
Cause of Spill: Platform explosion
Oil Type: Louisiana Crude

Summary: On December 1, the well B-21, a 424 bbl/day capacity well, exploded and caught fire, rupturing 12 feet above the waterline. Burning oil covered the surface within 50 feet of the well. An intensive effort was undertaken to drill relief wells and cap the well, which continued until April when the well was finally capped. Flow rates from the well varied from the initial 424 bbl/day capacity on December 1 down to 20 bbl/day by April 16.

Initially, most of the oil was burned within 50 ft of the platform. By January 20, the slick

extended two miles southwest of the fire, producing a rainbow sheen for another six miles. Throughout February - March the slick became progressively smaller as it was dispersed by winds and currents.Additional information on countermeasures and cleanup methods is sketchy. Dispersants (Corexit 7664) and oil herders were used during the response as well as mechanical recovery.

<u>Applicability of Alternative Burning Techniques:</u> In the early stages of the spill, much of the oil was consumed by the fire at the platform. The fire at the platform indicates the oil was burnable. If the fire had not occurred, the spill would represent an opportunity for use of a Concept I - III device, particularly during the first two months when spill rates were higher (before the relief wells were completed) and the slick well defined. The moderate flow rate (424 bbl/day or less) would make the use of Concept III feasible, although the platform is located in an area where a Concept I or II device might generally be pre-staged.

Tampa Bay Spill

Date of Spill: 08/10/93
Location of Spill: Entrance to Tampa Bay, FL
Volume of Spill: 8,619 bbl
Cause of Spill: Collision of three vessels
Oil Type: No. 6 Oil (7857 bbl) and gasoline, jet fuel, and diesel (762 bbl)

<u>Summary</u>: On April 10, 1993, three vessels collided at the entrance to Tampa Bay - the phosphate carrier M/V BALSA 37, and two tug/barge combinations OCEAN 255 and B. No. 155. The collision resulted in a spectacular explosion on the OCEAN 255 resulting in the spilling of 762 bbl of gasoline, jet fuel and diesel (much of the cargo was consumed in the fire). The Barge B. No. 155 was holed causing a near instantaneous release of 7857 bbl of No. 6 fuel oil.

The bulk of the oil was initially carried offshore which allowed an intensive skimming operation which recovered over half the oil. On August 15, shifting winds drove the remaining oil ashore along a 14-mile stretch of beaches from St. Petersburg and North Reddington Beach, and into Boca Ciega Bay and the Intercoastal Waterway. Eventually, 20 miles of shoreline, seawalls, docks and residential canals were contaminated requiring an extensive shoreline cleanup effort.

<u>Applicability of Alternative Burning Techniques:</u> The near instantaneous release of the No. 6 oil, its doubtful burnabilty, and the proximity of populated areas would undoubtedly preclude the use of the alternative burning measures.

Trimar Marine Well 327

Date of Spill: 08/08/73
Location of Spill: Gulf of Paria, Venezuela
Volume of Spill: 36,650 bbl
Cause of Spill: Well blowout
Oil Type: Venezuelan Crude

Summary: Information on this spill is limited. The well suffered a blowout on August 8 and spilled oil at a rate of 2,000 bbl/day until August 12 when the oil sanded up. Slicks extended up to 6 miles from the well, but were composed of patches and thin sheen. On August 10, response personnel began injecting water into the well to lessen the chance of ignition, such that the oil came out as emulsion. Countermeasures focused on dispersant application, with 3,300 gallons of dispersant used.

Applicability of Alternative Burning Techniques: The limited duration of the release, lack of a cohesive slick, and oil emulsification make this spill less of a candidate for alternative burning approaches (Concepts I - III) than the others. In a similar spill of longer duration, the Concept III device could be employed as it could be transported by air to Venezuela, and rapidly deployed.

YUM II/ Zapoteca

Date of Spill: 10/10/87
Location of Spill: Bay of Campeche, Gulf of Mexico
Volume of Spill: 58,640 bbl
Cause of Spill: Well blowout
Oil Type: Light Crude

Summary: On October 10, the blowout preventer on failed, causing a blowout and oil discharge onto the platform where it subsequently caught fire. The fire was extinguished on October 17, but as of October 28 the well was still spewing a mixture of gas and crude oil 60-100 ft in the air, at an estimated discharge rate of up to 30,000 bbl/day. The release was halted on November 30. From October 10 through 18, the slick was mostly sheen (much of the oil was undoubtedly burned) extending 55 miles from the spill site. On October 24 - 26, after the fire was extinquished, slicks composed of orange-brown mousse were observed extending up to 95 miles from the spill site.

Details on countermeasures and cleanup operations are sparse. A boom was dragged through the slick on October 17 to break it up. Several shimmers were also employed.

Cleanup operations were undoubtedly limited by the dispersed nature of the slick.

<u>Applicability of Alternative Burning Techniques:</u> Information on this spill is limited. Although the flow rate is cited as up to “30,000 bbl/day”, it is clear that the actual flow rate was much less (only 60,000 bbl spilled over 50 days which averages to only 1200 bbl/day). The slick was composed of patches of emulsified il. It is not clear that the spill as it occurred would have been a candidate for alternative burning techniques.

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Appendix E

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