NIST Special Publication 935

In Situ Burning of Oil Spills Workshop Proceedings

New Orleans, Louisiana, November 2-4, 1998

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National Institute of Standards and Technology
Gaithersburg, MD 20899-8644

February 1999

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COVER

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

ISBN No. 1-886843-03-1
National Institute of Standards and Technology Special Publication 935
Natl. Inst. Stand. Technol. Spec. Publ. 935, 114 pages (February 1999)
CODEN: NSPUE2

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1999

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402-9325

ALTERNATIVE APPROACHES TO *IN SITU* BURNING OPERATIONS

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BACKGROUND AND OBJECTIVE

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

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

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

APPROACH

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

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

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

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

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

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

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

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

RESULTS

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

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

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

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

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

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

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

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

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

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

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

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

<u>Concept - III Modular, Transportable Oil Burning Barge</u>

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

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

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

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

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

Concept IV - Air Bubbler System for Shallow Water

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

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

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

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

Concept Application Hindcast Analysis

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

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

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

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

CONCLUSIONS

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

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

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

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

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

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

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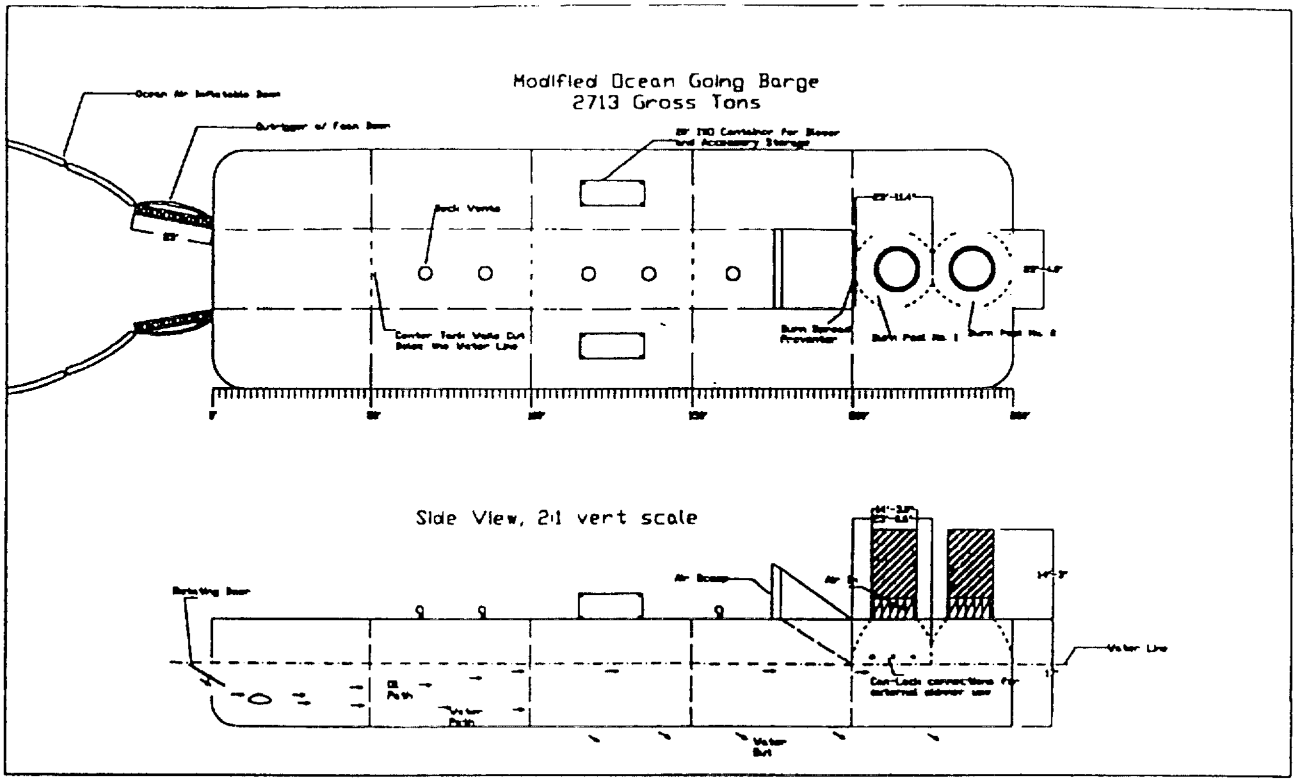

Figure 1. Basic Design for Concept IIA- Oil Burning Barge With Emissions Control Device

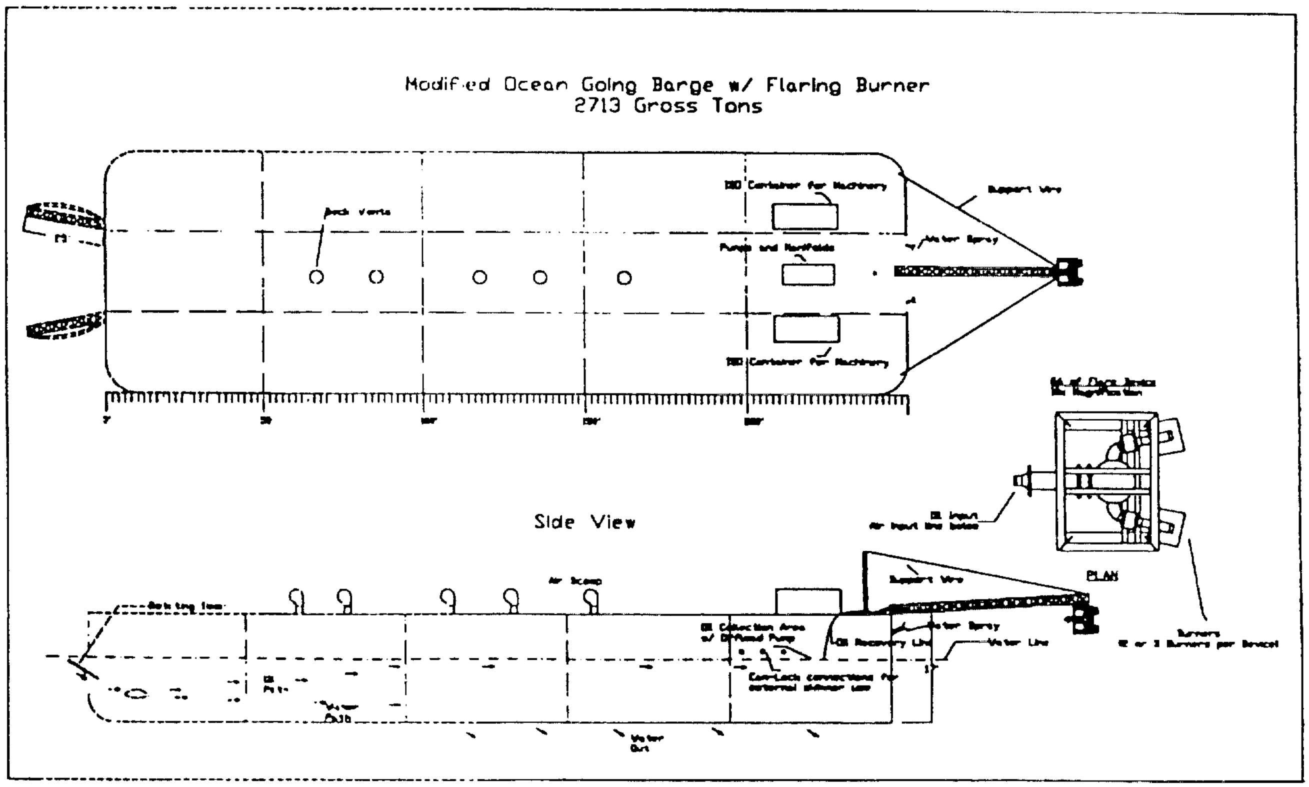

Figure 2. Basic Design for Concept IIB - Oil Burning Barge Equipped With Flaring Burner

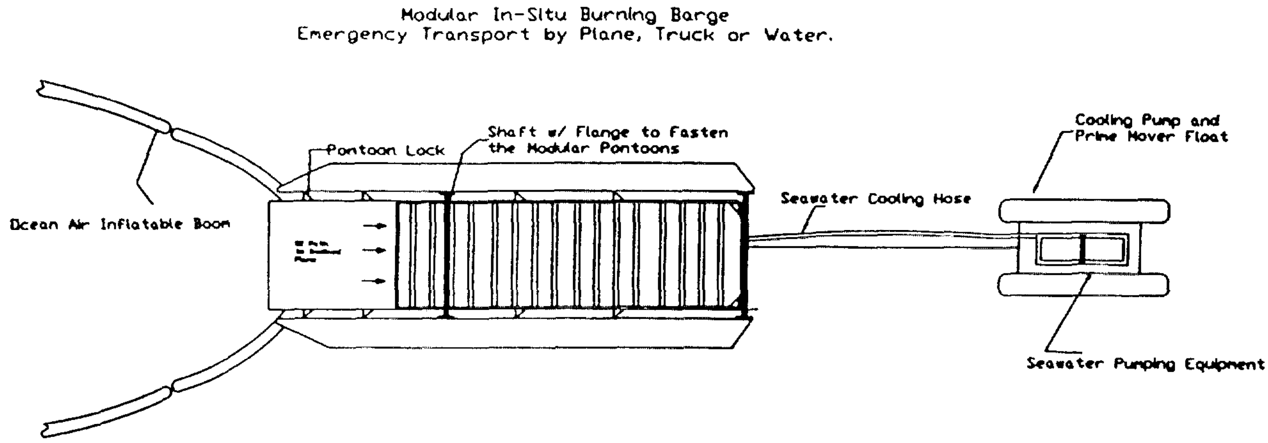

Figure 3. Basic Design for Concept III - Modular, Transportable Oil Burning Barge.

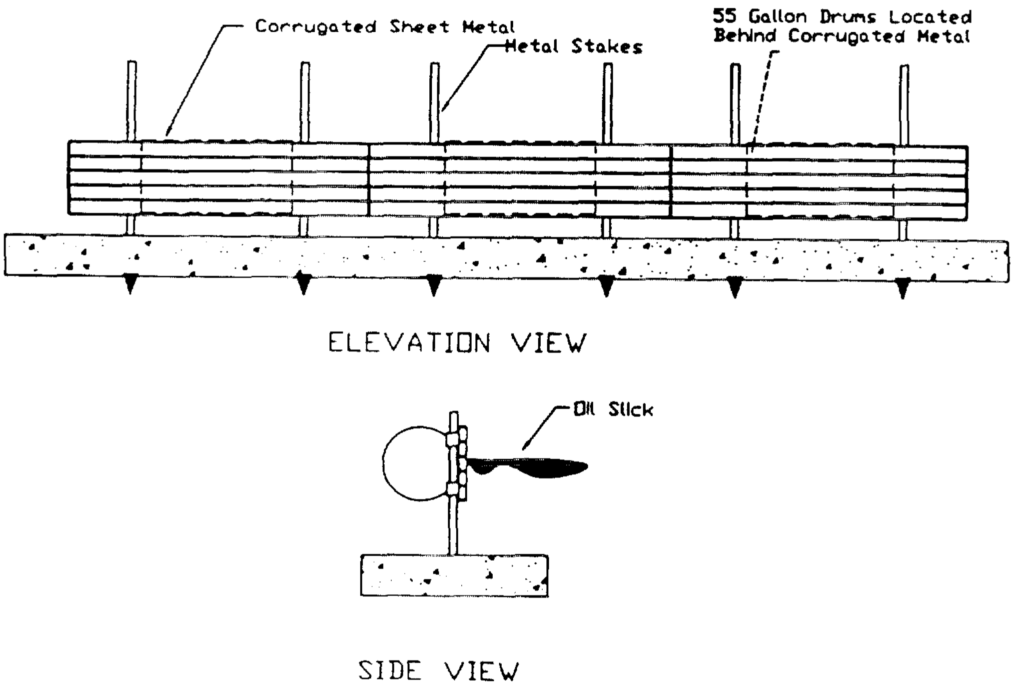

Figure 4. Basic Design for Concept V - Simple, Fire-Resistant, Shallow Water Fence Boom.