TEST AND EVALUATION OF A NEW AND UNIQUE FIRE CONTAINMENT BOOM

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ABSTRACT

During the fall of 1987, a new concept for fire containment boom was evaluated during burn tests in Hastings, Minnesota, and in Kenai, Alaska. The 3M Company used specially fabricated, high-temperature ceramic materials to develop a curtain boom with semi-solid flotation. The fire containment boom was designed to appear and function as a conventional boom with a sacrificial outer layer covering its internal fire-resistant components. Test sections of boom with a cylindrical buoyancy component 10 inches (25.4 centimeters) in diameter were formed into closed loops and subjected to a continuous flow of oil (heptane and Prudhoe Bay crude). The oils were ignited exposing the test booms to peak flame temperatures typically between 1400°F and 1800°F (800°C and 1000°C). Following tests with total exposures of 6 hours (with heptane) and 24 hours (with crude oil), the booms were found to have minimal thermally induced degradation of their ceramic components and no degradation of their primary structural members above and below water. The burn tests and subsequent sea trials in Port Canaveral, Florida involving 500 feet (152 meters) of fire boom reveal that the boom will survive prolonged exposures to burning oil and that the boom has good sea-keeping and oil-containment characteristics while under tow in light seas. This project has provided important information leading to the development of a unique oil spill containment barrier for controlling an accidental fire or for enhanceing a deliberate attempt to burn oil in situ.

BACKGROUND

During the past decade, several groups have seriously considered the elimination of spilled oil through in-situ burning (Battelle, 1979; Buist, 1987; Evans et al., 1987; Industry Task Group, 1983; Shell et al., 1983; and Smith and Diaz, 1985). Much of this work has demonstrated that large volumes of oil can be removed from a water-borne spill quickly and efficiently (Shell et al., 1984; Allen, 1987). The success of any in-situ burning operation, however, is strongly dependent on the flammability (or ease of ignition) of the oil and upon the oil's thickness during burning. It is essential, for example, that burning oil be maintained at a thickness of at least a tenth of an inch (2 to 3 millimeters) to sustain efficient combustion. Even under arctic conditions, such oil film thicknesses generally require the use of a fire-resistant barrier that can be used to completely encircle the spill or be used in conjunction with winds and/or currents to herd the oil into a limited containment zone.

Environment Canada. Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 11th. Proceedings. June 7-9, 1988, Vancouver, British Columbia, Canada, Environment Canada, Ottawa, Ontario, 185-199 pp, 1988.

A companion paper, "Comparison of Response Options for Offshore Oil Spills," (Allen, 1988) in these seminar proceedings deals with specific modes of use for a fire containment barrier. The reader is urged to examine that paper for operational considerations that 3M used in selecting materials and in designing a fire-resistant containment barrier. It was understood, for example, that under most conditions the deliberate elimination of spilled oil through burning should be used only after every mechanical removal technique available had been considered. In addition, it was hoped that such a floating barrier might prove to be an effective "fire break" in situations where an accidental petroleum fire might otherwise spread on water to neighboring vessels or facilities.

DESIGN AND PHYSICAL CHARACTERISTICS

The objective of the fire boom development program was to utilize the unique ceramic materials technologies of 3M to design a functional conventional curtain boom able to survive intense, long-duration burns.

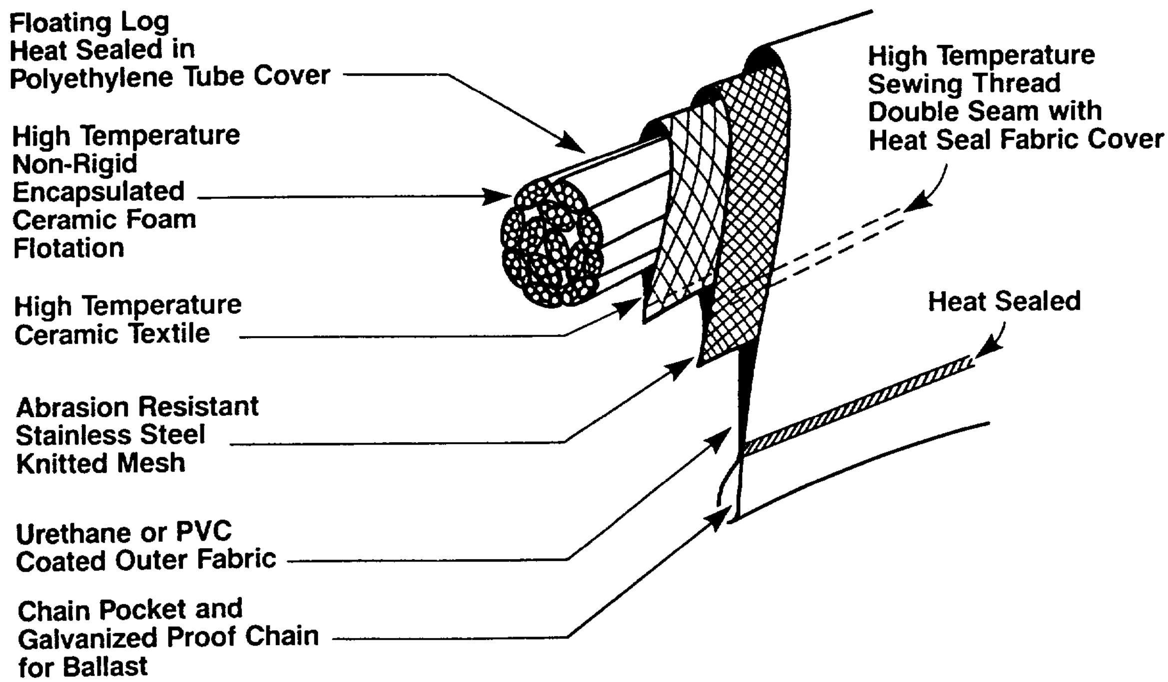
The results of numerous experiments and prototype tests led to the current 3M Fire Boom design. As shown in Figure 1, the 3M Fire Boom consists of a high-temperature, closed-cell ceramic foam held inside lineal pockets of stainless steel mesh. The foam-filled pockets (or cells) are combined to form a float log, which is covered with a heat-sealed polyethylene bag. The flotation logs are then covered with a layer of specially designed Nextel ceramic fabric. A layer of stainless-steel knitted-wire mesh is then positioned between the ceramic fabric and a surface layer of PVC-coated fabric similar to that used on conventional oil containment booms. The tension member is a 1/4-inch (6.35-millimeter) galvanized proof-coil chain held within a double-fabric chain pocket to improve abrasion resistance. Sections of boom are joined using standard Universeal™ connectors.

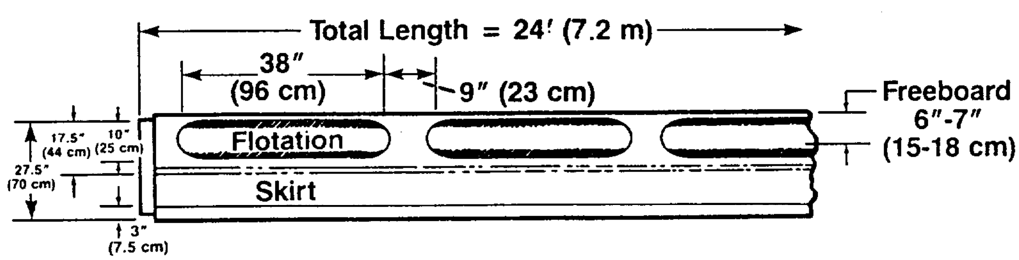
The boom configurations used during this phase of the development program involved two boom sizes: one with flotation sections 10 inches (25.4 centimeters) in diameter, weighing approximately 6-1/2 pounds per foot (3 kilograms per meter), and another 12 inches (30.5 centimeters) in diameter, weighing approximately 10 pounds per foot (4-1/2 kilograms per meter). 3M is currently working to reduce these weights considerably.

BURN TESTS

Six-Hour Exposure Test with Heptane

The six-hour burn test was conducted at the 3M Fire Training Center in Hastings, Minnesota, during September, 1987. The boom was 28 feet (8.5 meters) long, with a flotation diameter of 10 inches (25.4 centimeters). Each flotation log was approximately 38 inches (97 centimeters) long, with a 12-inch (30.4-centimeter) skirt. Thermocouples were attached at key points on the boom and on a pole at the center of the burn area approximately 8 inches (20 centimeters) above the water line (Figure 2). A continuous flow of heptane was fed to the burn area at a rate of about 1 gallon per minute (3.8 liters per minute) and then ignited (Figure 3). Thermocouple readings were recorded, with maximum temperatures exceeding 1500°F (815°C). After the test the boom was examined for fabric and mesh flexibility, fabric and seam strength, and float pocket integrity. Final inspections of these





Universeal™ Connector used on Fire Boom slide type connectors held in place with dual locking pins.

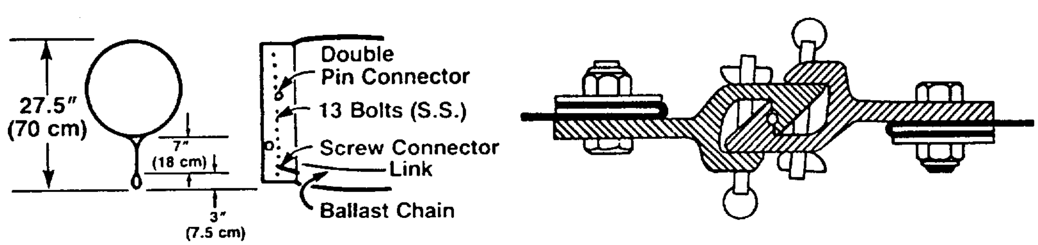


FIGURE 1 3M FIRE BOOM CONFIGURATION DURING KENAI TEST, OCTOBER, 1987

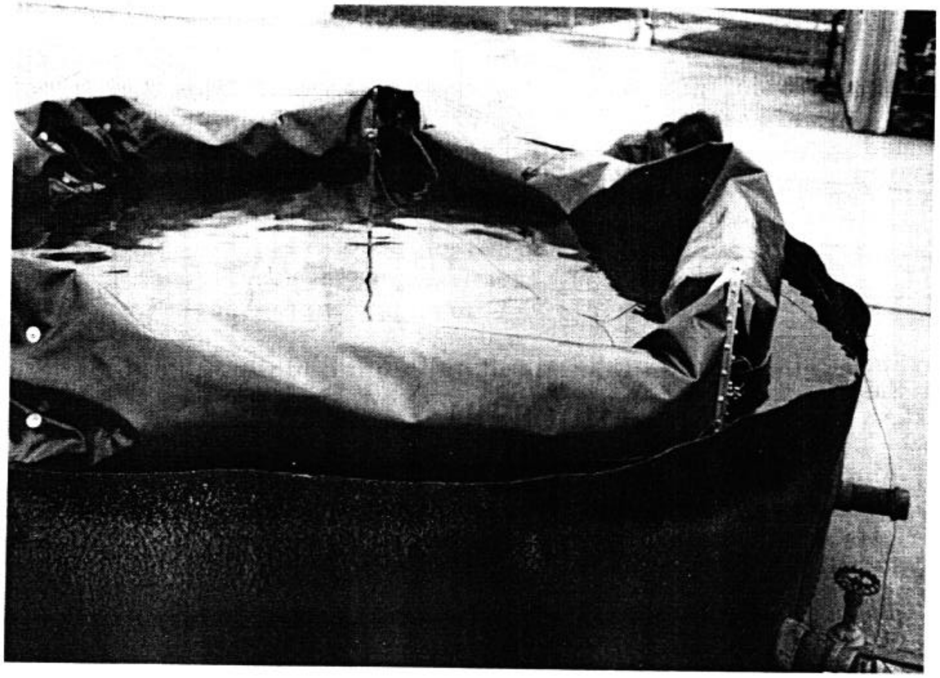


FIGURE 2 FIRE BOOM PRIOR TO 6-HOUR HEPTANE BURN TEST IN HASTINGS, MINNESOTA

FIGURE 3 FIRE BOOM AFTER IGNITION OF HEPTANE IN 6-HOUR BURN TEST

components revealed no sign of thermal stress, and lab testing of the fabrics showed very little loss of original strengths.

24-Hour Exposure Test with Crude Oil

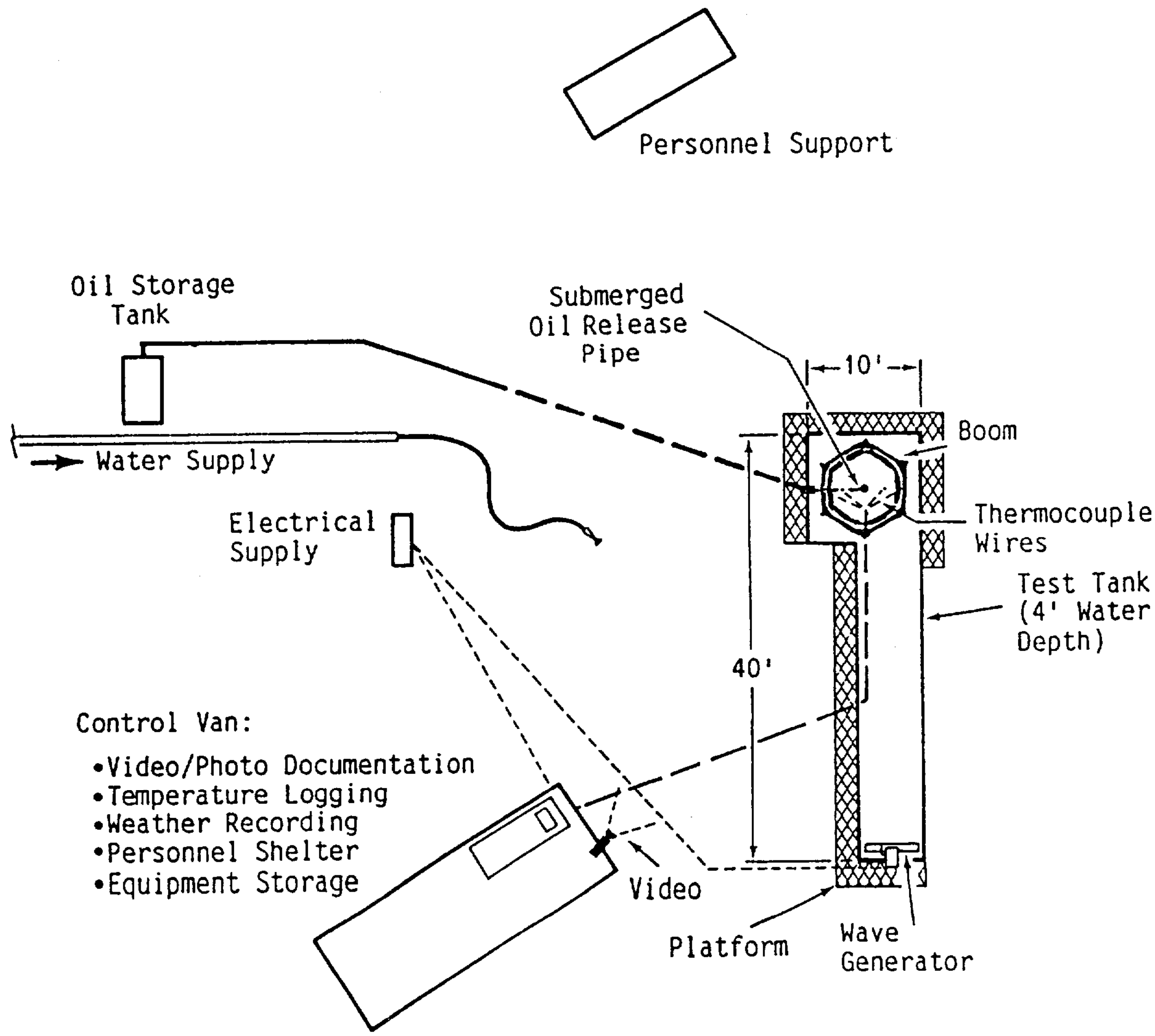
Objectives: The primary objective of the 24-hour test burn at Kenai, Alaska (October, 1987), was to evaluate the performance of the 3M Fire Boom during and following prolonged exposure to burning crude oil. The test included evaluations of internal as well as external resistance to fire; impermeability to oil before, during and following exposure to flame; structural integrity against tensile forces, bending motions and abrasion; and the ease with which the boom could be handled and transported before the burn and at its conclusion. Other assessments included the boom's freeboard before, during and after the burn, its resistance to impact with a sharp object (following 24 hours of exposure to fire), and its potential for reuse.

Location and Facilities: The test burn was conducted at the Kenai Community College Fire Control Training Center in Kenai, Alaska. Figure 4 illustrates the basic layout for test equipment and support facilities at the burn site. Mobile equipment was moved to the site for weather protection and to accommodate various storage and documentation needs. Approximately 2,000 gallons (7,500 liters) of Prudhoe Bay crude oil were stored on site and used during the 24-hour burn test. The crude oil was allowed to gravity-feed into a 1-inch (2.54-centimeter) pipe that provided a continuous flow of oil to the center of the boomed containment area in the test tank.

Test Procedures: The 3M Fire Boom used during this test had a flotation diameter of 10 inches (25.4 centimeters) and a total length of approximately 24 feet (7.3 meters). The boom was closed into a hexagonal shape within the 10-foot (3-meter) square portion of the test tank (Figure 5). The sacrificial layer used during this test was made of Urethane (23 ounces per square yard, or 780 grams per square meter); however, a second test was conducted later in the week using a PVC layer of the same weight. The tests included both materials in response to requests from potential Fire Boom users regarding their own preferences for an outer covering.

Single flotation logs nearly 3-1/2 feet (1 meter) long were used as flotation in the test boom in order to accommodate a closed loop of Fire Boom in the test tank. And, because of the amount of outer fabric needed to form a small closed hexagon, each log was separated by a fold (or pleat) of material that would not be necessary in any final boom configuration.

Before the 3M Fire Boom was set in the test tank, thermocouples were positioned at six locations on the boom and at four locations above and below water in the tank. The boom was then lifted into position within the tank so that the oil feed pipe was at the center of the area enclosed by the boom. Small subsurface wires held the boom in position to prevent winds from moving the boom away from the source of oil and to maintain the boom's orientation within the tank. Thermocouple wires were fed into the documentation van and connected to a multi-channel digital thermometer and scanner system. Temperatures at each thermocouple were logged frequently during the early stages of the burn and then at 15-minute intervals throughout the rest of the test.



Fire Containment Boom Test Facility

Location: Kenai Community College Fire Control Training Site, Kenai, Alaska

Test Tank: 40-ft long, 5-ft-high steel tank with 10 ft x 10 ft area for placement of boom.

FIGURE 4 KENAI, ALASKA, TEST FACILITY

Throughout the test burn, crude oil was fed to the contained area at between 1/2 and 1 gallon per minute (1.9 to 3.8 liters per minute). This flow rate provided sufficient oil for a continuous burn of the crude oil over one-half to three-quarters of the area within the boom. The resulting fire and boom performance were recorded using still photography (color slides) and two video cameras. Photo and video documentation was collected at the beginning and end of the test, at brief shutdowns of the fire for close-up inspection, and at one-hour intervals throughout the burn.

Throughout the test burn, air temperatures were typically between 32°F and 40°F (0°C and 5°C) at night, and between 40°F and 50°F (5°C and 10°C) during the day. Visibility remained good, with scattered clouds and intermittent light breezes of 0 to 3 miles per hour (0 to 1-1/2 meters/second). No rain fell during the 24-hour test burn.

Burn Test Results: Figure 6 shows the nature of the fire approximately one minute following ignition. Much of the outer, sacrificial (Urethane) layer is still in place on the side of the boom facing away from the fire. In Figure 7, several minutes later, the last portion of the sacrificial layer can be seen burning down to the water line.

During this early ignition stage and throughout the remainder of the test burn, peak flame temperatures were typically in the 1200°F to 1650°F (650°C to 900°C) range, with occasional excursions above 1800°F (1000°C). Depending on the wind and the nature of oil/residue accumulation within the boom, the location of the peak temperatures shifted around the fire containment area. Sometimes the fire would drop back to a fairly small burn area for a few seconds while fresh, cold crude oil would

FIGURE 5 FIRE BOOM IN POSITION PRIOR TO IGNITION OF CRUDE OIL

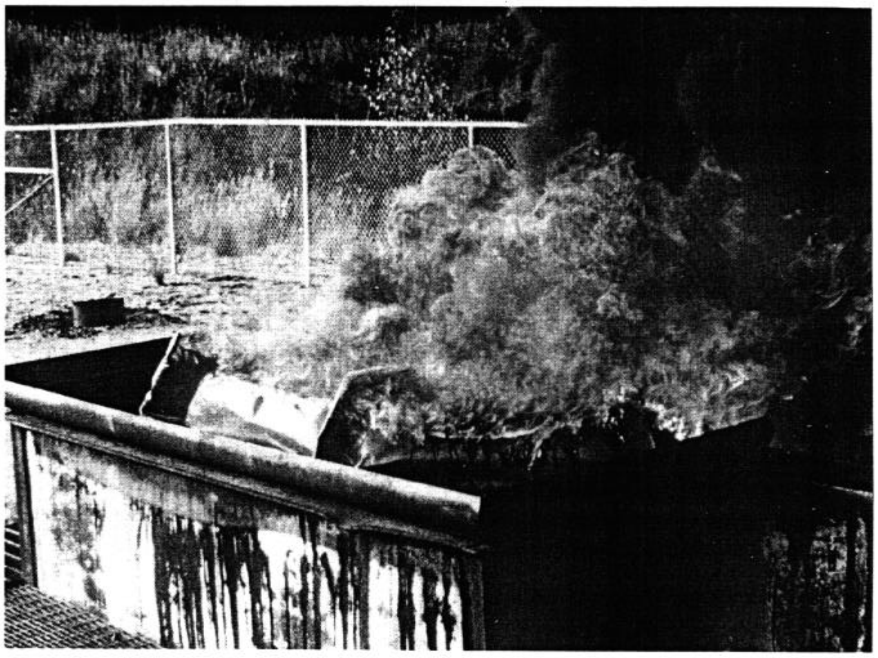


FIGURE 6 3M FIRE BOOM WITH BURNING OIL APPROXIMATELY 1 MINUTE FOLLOWING IGNITION OF THE OIL

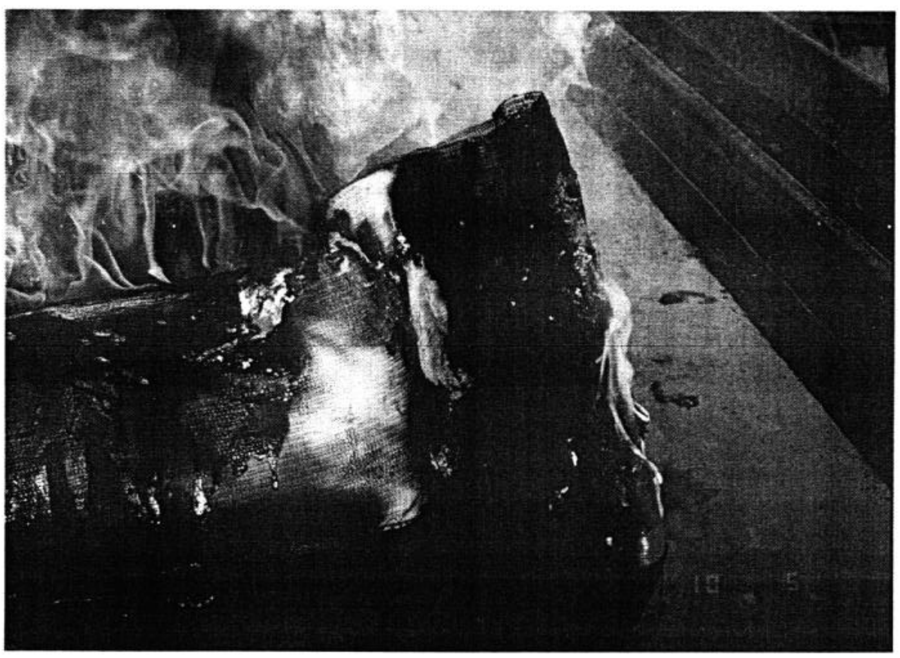


FIGURE 7 CLOSEUP VIEW OF THE FIRE BOOM AS THE LAST PORTION OF THE SACRIFICIAL LAYER IS BURNED OFF

bubble up and spread a few feet from the fire. The oil would heat up rapidly and release vapors that would then ignite and cause a rapid spread of intense fire over the entire containment area. This natural oscillation of burn size and intensity was noted throughout the test to be somewhat dependent on the temperature of the water directly beneath the fire.

One hour into the burn, the supply of oil to the test tank was shut off, thus allowing the fire within the boomed area to gradually go out. When it was safe to inspect the boom up close, it was apparent that the sacrificial layer was completely removed (as expected) on all sides of the boom above water. All other components of the boom appeared to be in excellent condition. The wire mesh and Nextel fabric were still quite strong and pliable. Figure 8 shows a close-up view of the boom with remnants of charred urethane and burned oil residue in small patches on the side of the boom facing away from the fire. The average freeboard of the boom was measured at between 6 and 7 inches (15 and 18 centimeters), approximately an inch (2 to 3 centimeters) less than the boom's freeboard prior to ignition. Such reduction in freeboard was expected since the removal of the outer sacrificial layer (supported by air captured inside) could no longer contribute to the overall freeboard.

Within a few minutes, the flow of oil to the boom was once again begun and the oil was ignited. As during the first hour of the test burn, a constant exposure to burning crude oil was established using the same feed rate. At times the intensity of the burn increased noticeably as water began to boil directly beneath the burning crude oil. Such boiling resulted in small eruptions of water vapor as bubbles began to form and build in pressure beneath the layer of oil. When the oil layer was sufficiently

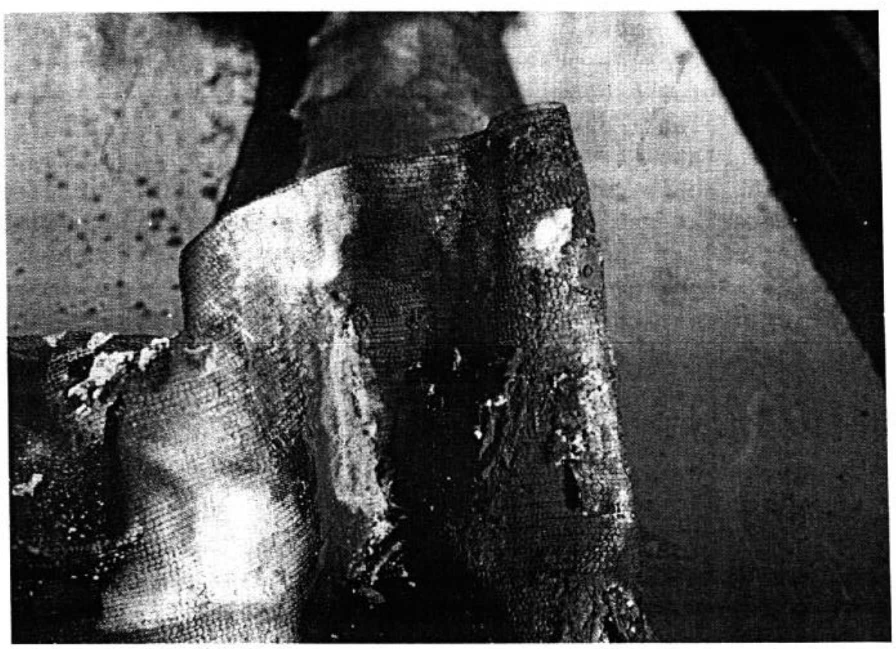


FIGURE 8 CLOSEUP VIEW AT THE 1-HOUR INSPECTION SHOWING THE SAME CORNER OF THE BOOM SEEN IN FIGURE 7

thick to require high pressures for vapor release, the eruptions blasted particles of hot and/or burning oil into the air. These particles substantially increased the size and intensity of the burn, resulting in the splattering of some oil onto the water surrounding the boom. Such splattering will likely be reduced in an actual open-water burn since moving subsurface waters will tend to disperse the heated water beneath the fire into the cooler water below.

Once again, at six hours into the burn test, the flow of oil to the test tank was stopped and the boom was examined. The condition of the boom during this inspection was basically as observed and described following the one-hour burn period. There were no signs of deterioration anywhere in the stainless steel mesh surrounding the flotation and ceramic (Nextel) fabric of the boom. The ceramic fabric was discolored in places where it had been exposed to the most intense and prolonged heat; however, the fabric was still pliable and showed no visual signs of significant thermal degradation.

Again, within a few minutes following the brief inspection of the boom, a continuous flow of oil was re-ignited and allowed to burn for several more hours. At approximately half way through the planned 24-hour exposure, it was decided that the fire would be shutdown for approximately 12 hours. It was felt that such a cooling-down period, followed by additional fire exposure, would be a realistic and important test that a fire containment boom might actually experience under real-world conditions.

Following the deliberate cooling down of all boom components, the flow of oil and ignition was once again initiated. Throughout the second half of the burn test, the boom looked and performed as it had during the first half. Though exposed to prolonged extreme temperatures and then cooled to near freezing, the boom remained flexible, impermeable and resistant to repeated exposures to burning oil.

Upon completion of the 24-hour exposure period, the Fire Boom was allowed to cool and then removed from the test tank. The boom was quite capable of taking the usual bending and twisting motions associated with such handling. It was also observed that there was no noticeable reduction in the resistance of the boom's wire mesh to abrasion. In fact, personnel on site could not tear or break the wire mesh with gloved hands. It was only with an axe that a small hole was produced through the wire mesh. Enlargement of the hole revealed that only one of the cells containing the foamed ceramic material was broken open as well. A second blow with the axe did open another cell; however, when picked up and shaken, the entire flotation section released only a small amount of foam material from two of the 14 flotation cells. It appeared that while a sharp object could puncuture the boom, such damage would not normally result in a catastrophic failure of the boom. It is very likely that the boom could have continued to maintain its freeboard, its impermeability to oil and its resistance to fire following the deliberate damage done to it.

Further inspection of the boom included a complete removal of one flotation section and a careful examination of the boom's below-water components. The flotation section removed was that which had been hit earlier with an axe. It was quite evident that those cells which had not been deliberately cut open were in excellent shape and that the ceramic float had suffered no apparent degradation of any kind. Examination of the below-water components also revealed that the boom remained impermeable to oil at and below the water line.

A second test was carried out a few days later with burning crude oil and a similar test boom, this time with a PVC outer sacrificial layer. All results were basically as noted for the earlier 24-hour burn; however, the PVC covering provided substantially more resistance to the fire. Even after many hours of exposure to the burning crude oil, the sacrificial PVC material remained intact several inches above the water line on the side of the boom facing away from the fire. This material provided an additional impermeable barrier against any movement of oil through the boom.

TOW TEST

Objectives

The primary objective of this phase of the program was to evaluate the performance of the 3M Fire Boom during full-scale deployment and towing operations. A boom 12 inches (25.4 centimeters) in diameter and 500 feet (152 meters) in length was used to obtain information on the boom's (1) ease of use, (2) roll and heave response during towing, (3) freeboard and susceptibility to splashover, and (4) general sea-keeping characteristics during conditions ranging from calm water to short-period wind chop.

Location

Port Canaveral, Florida, was selected as the tow test site. The Port Canaveral area offered excellent harbor facilities for deployment and for practice-booming of vessels, for towing in calm inland waterways, and for offshore operations as well.

Procedures

The packaging and transport of the Fire Boom to a boat-launching ramp at Port Canaveral was accomplished with a small flatbed truck and six workers. The same number of personnel were sufficient to deploy the 500 feet (152 meters) of boom from the truck and into the harbor. Two inboard workboats 25 feet (7-1/2 meters) in length were used for towing the boom, and a small 20-foot (6-meter) support boat was available for measurements, boom tending, and photographic work. Over a period of approximately 6 hours, the boom was towed by a single boat in a straight line at speeds up to 3 knots (1-1/2 meters per second) and by two boats in a U-configuration at speeds of 1/2 to 1-1/2 knots (0.25 to 0.75 meters per second).

During the towing operation, records were kept on tow-line tensions and boom performance. Underwater, surface, and aerial photographs were taken, while video coverage was obtained from the surface and the air. The boom's performance (freeboard, roll, heave, etc.) was assessed in natural sea states up to a light wind chop and in boat-generated waves of 2 feet (about 1/2 meter) while the boom was towed with and into the wind and waves.

During recovery of the boom, 14 men disconnected 50-foot (15.2-meter) sections at shoreside and carried them out of the water for draining, cleaning, and repacking on the flatbed truck. Observations and measurements were once again made on freeboard, ease of handling, susceptibility to abrasion/damage during recovery, and requirements for repacking and storage.

Results

Six workers and a single tow boat easily completed the deployment of 500 feet (152 meters) of Fire Boom from the storage containers and flatbed truck

(Figure 9). The entire length was deployed within 5 minutes, including the time required to complete the attachment of several connectors.

Once in the water, the boom was towed in a straight line toward one of the harbor's turning basins. The boom performed satisfactorily at several towing speeds. Measurements taken at several locations indicated a consistent freeboard of 10 to 11 inches (25.4 to 28 centimeters) at both flotation sections and at the boom's connectors. It should be recognized that the Fire Boom's freeboard following exposure to fire would be reduced by approximately 2 inches (5.1 centimeters).

In several tow tests with the boom in a U-configuration [typically with a 150-foot (46-meter) opening between the tow boats], the boom responded well to waves and to the currents generated by its own forward motion (Figure 10). At speeds of between 1/2 and 3/4 knot (0.25 and 0.75 meters per second), the boom's skirt and flotation chambers showed no signs of excessive roll. In addition, as waves (both natural and vessel-generated) came into contact with the boom, there were no indications of bridging or over-topping along the sides or apex of the boom's U-configuration (Figure 11). At speeds in excess of 1 knot (1/2 meter per second), there were the usual strong eddies behind the boom's apex that would normally be present with any boom. As expected, the tension recorded in the tow lines with normal swath widths and towing speeds remained between 200 and 400 pounds (890 and 1,780 newtons).

During all open-water towing tests, the boom demonstrated satisfactory sea-keeping characteristics based on close-up observations from the surface and from under water. The two comparably powered boats with 90-horsepower engines proved capable of carrying out all maneuvers that would normally be expected under actual spill conditions with the same boom length and comparable environmental conditions.

The recovery of the boom was completed using 14 people to lift one section (50 feet, or 15.2 meters) of the boom out of the water at a time. The recovery of the boom took approximately 40 minutes. The restowing of the boom on the truck for transport from the dock area required another 30 minutes. As in any actual spill situation, these recovery times are not excessive -- it is the deployment time (approximately 5 minutes with this boom) that would be most important.

SUMMARY

The 3M Fire Boom has been designed and constructed to function as a conventional bottom-tensioned curtain boom. While serving as a standard oil spill containment barrier, the boom can also be used as a fire-resistant barrier for the containment of burning oil on water. The internal components of the boom consist of high-temperature ceramic materials that are held in place and strengthened with stainless-steel wire mesh. The boom's outer PVC covering is intended as a sacrificial layer that would be at least partially removed along any section of the boom exposed to fire.

The Fire Boom has undergone full-scale tests during which contained heptane and crude oil layers have been burned with total exposures ranging from 6 hours to 24 hours. Tests have also been conducted with a full 500 feet (152 meters) of fire boom towed in varying configurations under calm-water harbor conditions to offshore seas involving short-period waves of one to two feet (approximately 1/2 meter). These tests revealed that the fire boom is capable of functioning as an effective containment barrier with

FIGURE 9 WORKERS DEPLOYING FIRE BOOM FROM FLATBED TRUCK INTO THE HARBOR

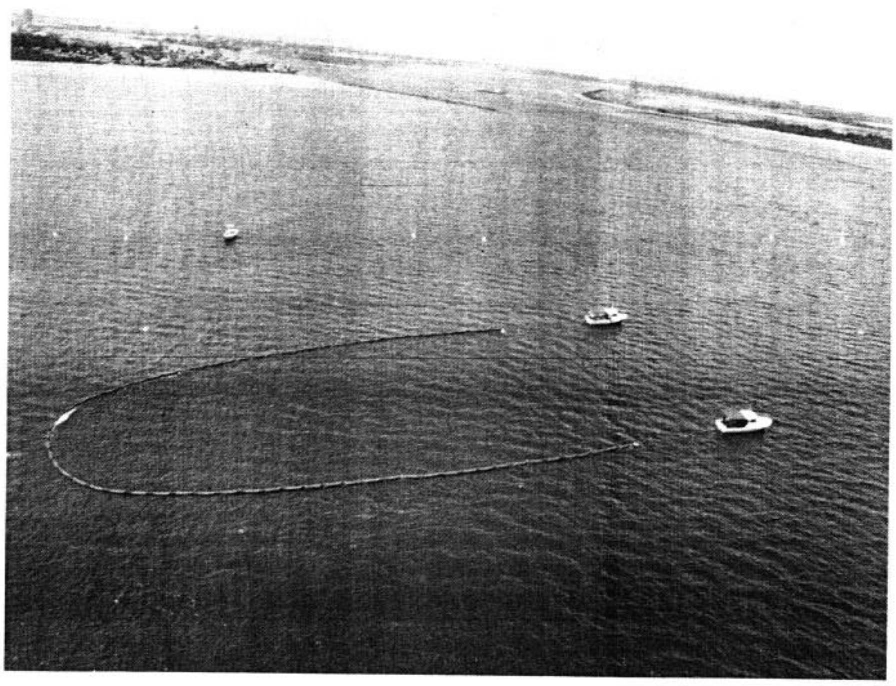


FIGURE 10 AERIAL VIEW OF FIRE BOOM WHILE UNDER TOW IN A U-CONFIGURATION

good wave-riding and towing characteristics. In addition, the boom is capable of surviving long-duration burns of oil contained and held against the barrier for extended periods of time.

REFERENCES

Allen, Alan A., 1987, "Test and Evaluation of the Helitorch for the Ignition of Oil Slicks," in Proceedings of the Tenth Arctic and Marine Oilspill Program Technical Seminar, Conservation and Protection, Environment Canada, pp. 243-265.

Allen, Alan A., 1988, "Comparison of Response Options for Offshore Oil Spills," Proceedings of the Eleventh Arctic and Marine Oilspill Program Technical Seminar, Environment Canada.

Battelle, 1979, Combustion: An Oil Spill Mitigation Tool, prepared for the U.S. Department of Energy, Washington , D.C., Contract No. EY-76-C-06-1830.

Buist, I.A., 1987, "A Preliminary Feasibility Study of In-Situ Burning of Spreading Oil Slicks," in Proceedings, 1987 Oil Spill Conference, American Petroleum Institute, U.S. Environmental Protection Agency, and U.S. Coast Guard, pp. 359-367.

Evans, D., G. Mulholland, D. Gross, H. Baum, and K. Saito, 1987, "Environmental Effects of Oil Spill Combustion," in Proceedings of the Tenth Arctic and Marine Oilspill Program Technical Seminar, Conservation and Protection, Environment Canada, pp. 91-130.

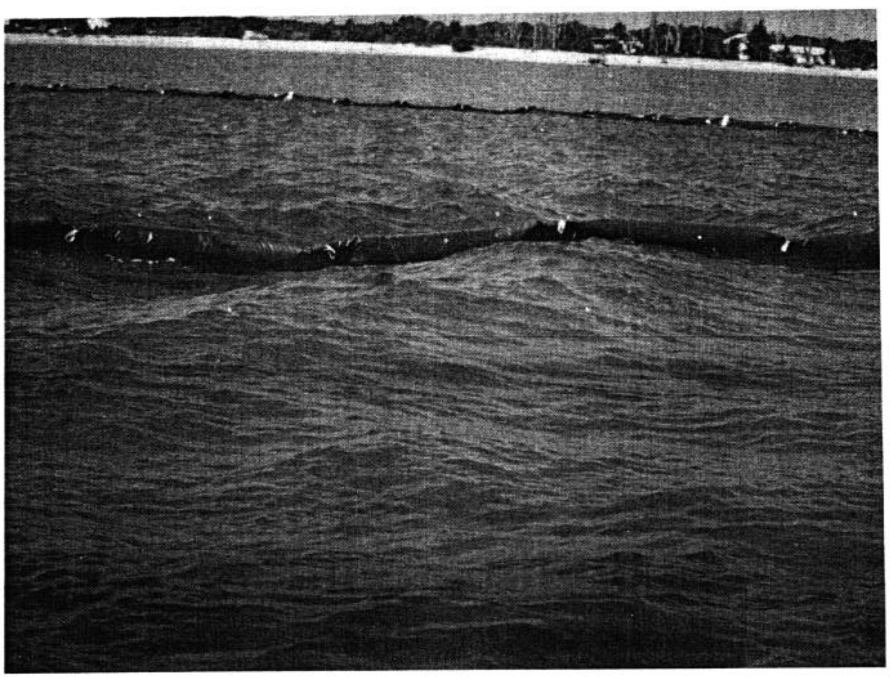


FIGURE 11 RESPONSE OF BOOM TO WAVES WHILE UNDER TOW

Industry Task Group, 1983, Oil Spill Response in the Arctic: An Assessment of Containment, Recovery, and Disposal Techniques, Amoco Production Company, Exxon Company USA, Shell Oil Company, and Sohio Alaska Petroleum Company, Anchorage, Alaska.

Shell Oil Company, Sohio Alaska Petroleum Company, Exxon Company USA, and Amoco Production Company, 1983, Oil Spill Response in the Arctic, Part 2: Field Demonstrations in Broken Ice, Anchorage, Alaska.

Shell Oil Company, Sohio Alaska Petroleum Company, Exxon Company USA, and Amoco Production Company, 1984, Oil Spill Response in the Arctic, Part 3: Technical Documentation, Anchorage, Alaska.

Smith, Nelline K. and Anibal Diaz, 1985, "In-Place Burning of Prudhoe Bay Crude Oil in Broken Ice," in Proceedings, 1985 Oil Spill Conference, American Petroleum Institute, U.S. Environmental Protection Agency, and U.S. Coast Guard, pp. 405-409.