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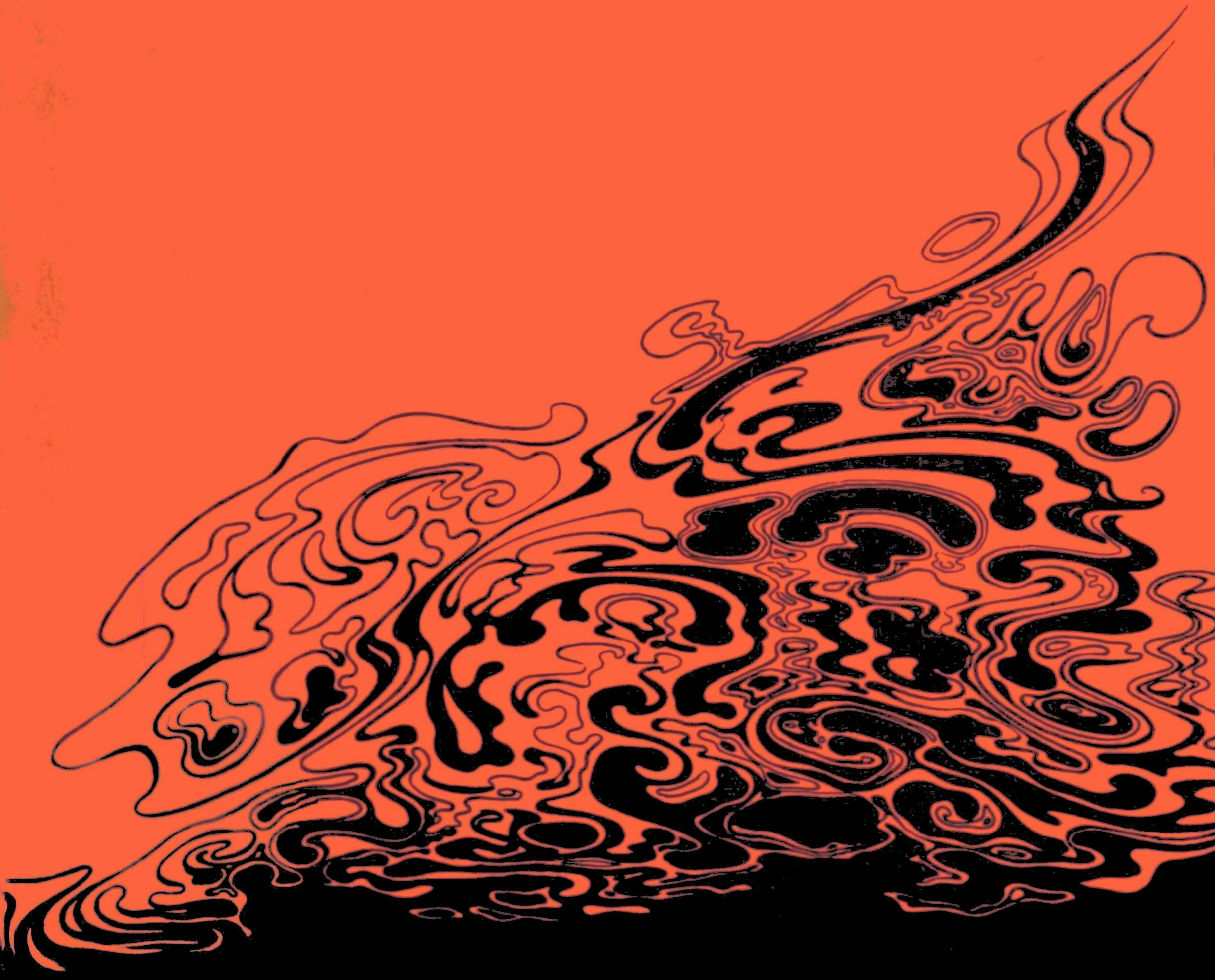
TESTING AND EVALUATION OF OIL SPILL RECOVERY EQUIPMENT



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TESTING AND EVALUATION
OF
OIL SPILL RECOVERY EQUIPMENT

by

Main Port Authority
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for the

WATER QUALITY OFFICE
ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

This report summarizes results of a project for testing and evaluating representative samples of oil spill control equipment. It presents a detailed analysis of the capabilities and limitations of all equipment tested together with recommendations for further developments. Suggestions for various techniques for deployment and operation of the equipment under varying ocean conditions are included.

The report is directed toward mechanical means for removing spilled oil from harbors and adjacent waters and an Appendix described results obtained under conditions of 30K winds and 8' waves in the Gulf of Mexico in March, 1970.

Tests reported include evaluations of mechanical booms, air barriers, 5 types of skimmers and several alternative arrangements of oil recovery and disposal systems. A design for an articulated skimmer adaptable to rough water operations is included.

Appendices to the report offer suggestions on effective measures for enlisting community support for oil prevention and clean-up programs.

The report urges industry to take the initiative to provide complete integrated systems for oil spill clean-up operations under both controlled and emergency conditions and available for use in all portions of the ocean.

This report was submitted in fulfillment of Contract 15080 DOZ between the Federal Water Quality Administration and the Maine Port Authority of Portland, Maine.

Key Words:

Curtain Booms
Fence Booms
Air Barriers
Oil/Water Mix
Skimmers
Throughput Capacity
Oil/Water Separation
Rate-of-rise

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LIST OF EXHIBITS

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The basic objectives of Project 15080 DOZ have been accomplished.

1. Commercial equipment for oil spill clean-up has been tested and evaluated to determine its capabilities and limitations.

2. Two designs of experimental Air Barrier equipment have been tested.

3. A working model of a rough water skimmer has been built and tested to determine the practicality of its design.

4. Broad specifications for an equipment system for major oil spills have been outlined.

In addition to those required tasks, several other accomplishments have resulted.

1. Modifications to existing oil spill equipment have been suggested to manufacturers. In many cases these have been adopted and incorporated in the new models.

2. Techniques developed during the testing program contributed substantially to the successful clean-up of the Louisiana oil spill in February and March of 1970.

3. The equipment industry has been made aware of some basic engineering concepts in the design and operation of spill clean-up equipment. They relate to

    a. Limitations to the containment capacity of a boom.

    b. The need for very slow relative speed of boom and oil slick in containment operations.

    c. Importance of rate-of-rise factor in designing clean-up equipment.

4. A procedure for aerial reporting of oil spills has been announced by District 1 (Boston) of the U.S. Coast Guard. (Described in detail in Annual Report of this project dated October 30, 1969.)

Conclusions and Recommendations derived from evaluation tests, observations, practical experience and studies are summarized below and are detailed in the appropriate sections of the report.

MECHANICAL BARRIERS

Conclusions

1. The use of a boom to control the movement of an oil slick can accomplish these tasks:

    a. If complete encirclement is possible the boom can

        1) Prevent further spread of the slick, and

        2) It can contain a large amount of oil - up to at least 2" of film thickness - as long as wind and wave permit.

    b. As a barrier across the path of a spill, a boom can

        1) Delay passage of the slick until depth of oil pool against the arc of the boom approaches two-thirds of the draft of the boom, or

        2) Until current and turbulence pull oil under the boom.

    c. Used as a sweep or trawl, the boom can

        1) Gather pools of surface oil in the arc of the boom so that skimming operations can be effective in those areas.

        2) Compact widely scattered puddles of oil or very thin films so that the efficiency of skimming can be improved.

        3) Tow or pull limited areas of slick from one location to another to avoid sensitive areas or to reach fixed oil-removal installations.

d. Used as a means of guiding the flow of an oil slick, the boom can

1) Divert the flow of a spill by as much as 20° from its natural path.

2) Lead a slick to the area where skimmer equipment is operating.

3) Limit the spread of a flowing spill in the area near the source.

2. For use in rough water, a minimum of 12" of freeboard is essential to reduce over-flow by surface waves and wind-driven spray.

3. Present designs can be effective when operated by trained personnel, but continued development of accessories and easier handling techniques are needed.

4. The overall evaluation of various styles of mechanical booms suggests that

   a. The curtain booms can be effective in shallow water and calm wind and wave conditions. As such, they offer very good cost effectiveness in protected waters.

   b. The light fence types offer the greatest protection and versatility for most situations, though their effectiveness may be very limited in shallow waters. (Less than 2 feet.)

   c. The heavy fence types are handicapped by heavy weight, and the need for mechanized handling equipment but their extra freeboard and stability can be very valuable in rough water conditions.

Recommendations

The following items should be considered by any supplier or manufacturers of boom equipment:

1. Improve the part that the boom can play in a complete clean-up system by

   a. Making it compatible with other equipment.

   b. Making it compatible with other booms.

c. Increase the ease of launching and recovery from a work boat or dock.

d. Design the boom to assist the clean-up operation - whether by skimmer, chemical or other device.

2. Improve its ability to exert more force against an oil spill.

a. Consider the addition of air or water jets to augment its abilities as an inert barrier.

b. Consider the aerodynamic possibilities of the freeboard structure as an assist in rough water.

3. Explore the use of multiple booms, with a secondary structure to act as

a. A channel to pick up small patches of oil which may get past the primary structure.

b. An auxiliary structure to act as a wave damper in choppy water.

4. Designers should explore the use of a material to limit the accumulation of marine growth on a boom, and should provide a method for cleaning such growth from a boom.

5. More attention needed on leak-proof fastening of booms to docks, boats and skimmers.

AIR BARRIERS

Conclusions

1. Air Barriers hold real promise for fixed installations across slips and parallel to unloading docks, for

a. Continuous stand-by operation at reduced air pressures should keep the hose ready for instant use, with maximum air pressure to be used only in emergencies.

b. The Air Barrier generates its strongest horizontal forces at or near the surface of the water. Vertical forces are also present, but their effect on oil spills needs additional research.

c. The sub-surface air curtain can partially divert sub-surface tidal currents of low velocity.

d. An air barrier can be almost as mobile as a mechanical barrier. Compressors, buoys and other accessories for operating an air barrier can be ship-mounted without undue difficulty.

e. The Air Barrier's ability to contain or divert oil in rough water has been tested by the manufacturer but results have not yet been published.

2. Some models should be sufficiently versatile to operate in several different applications.

   We realize fully that a general purpose model might entail a compromise with some engineering refinements which could be realized if the barrier were engineered for a specific task.

3. The Air Barrier may perform effectively in rough water conditions where the full force of surface waves and wind would not be exerted against the air supply pipe suspended sub-surface.

4. An Air Barrier used to surround a ship at a pier or at a single-point-mooring has some potential economic advantages as follows:

   a. Moderate installation costs

   b. Minimum manpower to activate and monitor its performance

   c. Will not limit the access of supply and work boats to the tanker

   d. Not susceptible to accumulation of ice in freezing weather

Recommendations for Further Testing and Development

1. The potential for permanent installations should be researched in more detail because of

   a. Possibility of low installation costs and low upkeep

   b. Possibility of using an air source which could be inter-changeable with other productive work when the air barrier is not required

   c. The barrier can be quickly and effectively activated by one man when needed

2. The potential of a mobile air barrier should be explored.

3. Rough water performance needs further research and demonstration.

SKIMMERS

Conclusions

1. Improved skimmer designs are needed:

    a. For rough water operations

    b. For high-speed pick-up of thin oil slicks spread over wide areas.

2. For massive oil spills, a through-put of 500 gpm or more is needed.

3. Most versatile design at time of this report seems to be the circular sump with a fixed or adjustable weir.

4. The endless belt "separating" skimmers have good potential for small spills in protected waters.

5. Dependable pumps, motors and accessories are essential for good skimming operations.

6. The skimming process, by itself, will not generate a surface flow of oil for any great distance. 6' to 10' seems to be the maximum at present.

7. The skimmers must go to the oil, or the oil must be brought to the skimmers.

8. Skimmers should have a high degree of compatibility with all other units in the system.

Recommendations

1. The development of improved skimmer designs should be accelerated until there is high volume capacity at strategic points near all petroleum centers.

2. One major objective is the skimming of massive spills in rough water conditions.

3. Another objective is the skimming of very thin slicks spread over wide areas.

4. Optimum performance toward these two separate objectives may require the use of dis-similar skimming principles.

RECLAMATION AND DISPOSAL EQUIPMENT

Conclusions

1. In any system of oil recovery and disposal, primary separation of the oil from the water should be introduced as early in the system as possible so that the problem of handling large volumes of oil/water mix is minimized.

2. Under most conditions, and with most types of oil, the gravity separation system is so simple and dependable that it should be given first consideration.

3. When and if shipboard separators (such as centrifuges or other techniques become available), such equipment should be introduced into the system at the earliest possible point to reduce the volume of liquid to be handled.

Recommendations

1. The ultimate objective of the recovery and disposal system should be to deliver the largest possible quantity of reclaimable oil to an oil refinery which can receive it.

2. The use of high pressure and high efficiency oil burners should be explored as a method of ultimate disposal of non-reclaimable oil sludges.

3. At the present state of the art, the design and operation of equipment to receive oil from the skimmer pumps and to handle it through ultimate disposal will depend on the type of equipment which is available at or near the location of the spill. In most areas where oil is being handled or transported in any volume, there is probably an adequate inventory of pumps, piping equipment, valves, tanks, and other accessories which can be mounted on surface craft or assembled at strategic shoreside locations so that systems such as described above or variations of them can be put together and operated effectively.

4. It is suggested that attention be given by government and industry to providing specially designed shoreside separator units. Vessels carrying petroleum

products could then tie up at place of loading and discharge the remaining ballast into separator tanks rather than discharging ballast into the sea. These units would be strategically placed at loading points.

(Note: This type of installation was called for in a Presidential message delivered on May 20, 1970.)

A CLEAN-UP SYSTEM FOR MAJOR OIL SPILLS

Conclusions

1. The type of equipment described has been proved to be effective up to the limits specified.
2. Basic clean-up systems built around the equipment specified would constitute effective systems to the limit of their capacities. (Equipment should include both weir skimmers and belt or disc skimmers.)
3. Individual systems, as described, would provide effective clean-up capacity, adequate for many locations where small spills might occur.
4. High mobility of the individual systems would permit quick concentration of multiple units to combat massive spills.

Recommendations

1. Pending the development of major advances in technology, units as described should be placed at strategic locations throughout the United States.
2. Action should be initiated to install such units (or the essential elements thereof) on all tankers operating on routes where land based equipment is not close at hand.

COMMUNITY RESPONSE TO THE OIL SPILL CLEAN-UP PROBLEM

Conclusions

A well organized community group, dedicated to the prevention of oil spills always and to immediate and effective clean-up of oil spills when they do occur, is the best guarantee of continued progress in the controlling of oil pollution on navigable waters.

PREPARATION FOR THE TESTING PROGRAM

Review of the State of the Art

Early in 1969 a literature review was initiated to develop background material on oil spill control technology. Coverage of the subject at that time was found to be sparse and few comprehensive reports were available. The review of literature has continued steadily throughout the project so that today there are many more reports on the major spills, technology for using equipment and studies of various aspects of oil spill phenomena. Universities, government agencies in the United States and Abroad, the petroleum industry and equipment suppliers have become major sources of information on the subject and an increasing amount of valuable data has been collected in our files. (See Bibliography)

In addition to the continuing search of literature, personnel attended meetings and conferences on many aspects of the problem and maintained contact with many groups and individuals who had experience with practical operations. Locally, these included Coast Guard personnel, members of the Maine Port Authority, Portland and South Portland Fire Departments, local marine contractors and barge and tanker operators.

On a broader front, personnel have attended a series of demonstrations and conferences by suppliers of equipment and materials and by local or regional groups engaged in organizing and operating oil spill prevention and control programs. The FWQA has been a continuing source of information and has supplied several documents relating to major oil spills and to equipment and procedures for combatting them.

A review of the information which was available from all sources indicated that there was very little definite knowledge on many phases of the testing program and there were no generally accepted standards against which equipment could be evaluated.

Technology for making comparative tests of equipment designs was almost non-existent.

The forces which are active in an oil spill had not been catalogued in a comprehensive manner and the few scientific treatises which were available presented very little information which could readily be used by lay personnel.

Consequently, it was necessary for the project to design its own testing laboratory, develop necessary techniques of testing procedures in order to arrive at definite evaluations and conduct additional research into all phases of the oil spill cycle from initial overflow to final clean-up.

Equipping a Testing Laboratory

Operations planned required a test site having very special facilities. An area was leased in South Portland, Maine in a space which had previously been used for building and launching Liberty ships. Two ship launching basins 800' long by 80' wide were available with adequate parking and storage space alongside. The testing area was ideal for controlled experiments in smooth water conditions and it provided an effective base for observation and evaluation of testing procedures.

The area was large enough to maneuver boats and the floating equipment used in oil spill control work. The tidal testing basin was protected from violent winds under most conditions but occasional northerly winds provided wave conditions up to 4' inside the enclosed basin. Tides measured 9' to 12' in height and tidal currents adjacent to the testing basin approached 1K in velocity.

On-shore storage facilities were adequate and observation platforms adjacent the area provided sufficient height for good viewing of testing procedures and good camera angles.

Water in the testing basin was generally clean which permitted limited sub-surface observation without the need for sophisticated underwater technology or specially built viewing chambers. There was adequate access to the testing basin for the power boats and other floating vessels and equipment which were used in the program.

The basin was surrounded on 3 sides with solid cement docks so that oil spills could be created and cleaned up without the danger of spreading pollution to nearby shorelines.

Rough water conditions were conveniently available in Portland Harbor near the testing area and large ground swells and a wide variety of surface conditions were available just outside Portland Harbor about 2 miles from the testing area.

The testing area was enclosed by a cyclone fence patrolled by industrial security personnel of the lessor.

The basic items of floating equipment for laboratory use included a small wooden barge (12'x22') to serve as a work platform, a 16' work boat powered with a 15 H.P. outboard motor, a specially built floating platform on which a variety of instruments could be mounted and a floating fabric tank of 5,000 gallon capacity which was used for temporary storage and transportation of oil and water taken from the ocean during the clean-up tests.

Dockside equipment included a field office and an oil/water separating system of 2,000 gallon capacity.

The field office provided shelter and work space for personnel during the winter months and served as a store room for marine gear and equipment necessary to support the operation.

The oil/water separation system included two steel oil tanks, each of 1,000 gallon capacity, and fitted with a series of valves to provide selected drainage of oil and water levels.

Sixteen hundred feet of air barrier hose was purchased and installed in various configurations around the basin both for testing purposes and as a barrier to prevent oil spilled in the basin from flowing out into the ocean.

Details of the operation of the equipment described above will be found in following sections of this report.

Development of Testing Technology

The project moved into its testing area in March of 1969 and proceeded with the development of some basic technology for measuring the effectiveness of oil spill equipment.

Measurement of Ocean Currents

It was found immediately that there was no marine speedometer equipment available for accurate measurement of surface and sub-surface currents at the low velocities which would be encountered in the program. Suitable instrumentation was developed by modifying new designs of marine speedometers which were just coming on the market. The equipment uses strain gauges activated by a probe which can be positioned at the point on the surface of the water or below the surface where the reading should be taken. Reactions of the strain gauge are transmitted through a modified Wheatstone bridge circuit to a battery powered amplifier and the output can be read on a milliameter dial calibrated in knots and fractions thereof.

This equipment was proved to be accurate to tenths of a knot. Its accuracy could be checked from time to time against a measured 200' range inside the testing basin. The instrument probes could be mounted on boats or barges and on the equipment being tested in the program. Probes could also be supported on an instrument platform floating on the surface of the ocean and supported by sub-surface buoyancy so that wave action did not produce unacceptable fluctuations of the indicator.

This equipment proved valuable in measuring currents generated by air barrier equipment and measuring the speed at which oil containment booms could be moved through an oil slick without losing control of the contained oil. The technology will be described in greater detail in the section on Mechanical Booms and Air Barriers.

Measurement of "Rate of Rise"

The State of the Art search had disclosed no information on the rate of rise of oil in globule or droplet form as it emerges from an underwater position and floats to the surface. There is a recent report that some work has been done on this subject by the FWQA laboratories at Edison, New Jersey.

Rate of rise is of great importance in the design and operation of oil spill control equipment. In the past, designers of oil spill control equipment do not seem to have given enough attention to this phenomenon with the result that equipment depending on a rapid rate of rise has proved to be limited in its capabilities.

For example, a tanker might spill oil from the scuppers into the ocean twenty feet below. The oil could penetrate to a depth of fifteen feet or more, and might require from 20 to 30 seconds to return to the surface. If the tanker were moored in calm water, the oil would return to the surface at the point of entry. If the ship were moored in a 5 Knot current, slow "Rate of Rise" might cause the oil to surface 100 feet from the point of the spill, and a protective boom placed less than 100 feet from the hull of the ship would be ineffective.

Again, the "Rate of Rise" should be considered when designing equipment to tow or push a skimmer through an oil slick. The bow wave from a work boat might easily force the oil to penetrate the water to a depth of 4 feet, and the oil could require 6 seconds or more to return to the surface. Under those conditions a skimmer placed close to the bow could overrun the displaced oil before the oil had returned to the surface.

In recent developments designers are beginning to plan for this Rate of Rise factor and have provided the necessary time interval for the oil to return to the surface after being displaced.

In order to measure this rate of rise, various sizes of globules of oil were contained in bags of polyfilm or of thin rubber latex and submerged below the water. The containers were ruptured at a depth of 10' below the surface and the rate of rise of the contents was observed and timed with a stopwatch. It was found that visible globules of oil could be timed accurately through this crude but effective procedure.

It was observed that the large globules (ping-pong size and larger) rose at the rate of 1 second per foot while the smaller droplets (pinhead size) had a slower rate of approximately 1½ seconds per foot.

This observation is in line with the well known fact that oil in very tiny particles, such as in an emulsion, takes much longer periods of time to rise to the surface of a gravity separating column than oil which is still in large globules.

Measurement of Thickness of Oil Slick

No equipment or procedure for measuring a thickness of an oil film was available to the project although such information would be highly desirable.

A crude technique for accomplishing this was developed by modifying a standard 5 gallon can so that it could be submerged below an oil film and then raised gently through the surface so that a representative core sample of a section of the surface and the sub-surface water could be lifted out of the ocean in the drum and sent to a laboratory for analysis. Chloroform evaporation techniques made it possible to measure the quantity of oil in the area enclosed by the core sample and by this means the thickness of the film could be determined. (See Exhibit 1.)

Ambient weather conditions were important to the testing program and were measured by standard weather instruments mounted in a portable console which could be positioned in work boats to measure wind direction, velocity, temperature, barometric pressure and humidity at the site of the test as needed.

The accuracy of such observations could be checked by referring to records of the U.S. Weather Bureau at the Portland, Maine International Jetport approximately three miles from the site of most of our testing work.

Various types of photographic technique were used to record many phases of the testing procedures and construction details of the equipment being tested. A library of photos constitutes a comprehensive data bank of the project. In one of the special tests an attempt was made to evaluate the capability of infra-red photography and other highly sensitive films. Both infrared and Tri X Pan film showed excellent definition of the oil spill on the surface of the water. This is reported under Appendices

Analysis of the Forces in an Oil Spill

When oil is spilled into ocean waters the volume spilled is only one factor effecting the area which will be polluted.

The ultimate size of the spill and the direction which it travels will be determined by the resultant of a series of forces which act upon the oil. (Exhibit 2 .)

The forces operating vertically are gravity and the rate of rise of the oil. The latter is a function of the specific gravity of the oil and of the water in which the oil floats.

The horizontal forces which effect the spill include "the spread effect" which urges the oil to travel outwardly from the center of the spill, the "surface tension" of the oil which tends to hold the oil in one mass until other forces overcome it, "current effect" which is the influence of river or tidal current and "wind effect" which is the force exerted against an oil slick by surface winds.

In addition to the 6 forces listed above various types of marine activity can act upon an oil spill in an almost infinite variety of unpredictable combinations.

Wave action can push some portions of an oil spill above or below its normal position above or below the surface of the water.

The wake of a boat or turbulence from its propeller can generate violent combinations of forces in an oil spill so that oil is forced far below the surface and in some cases oil and water are forced into an emulsion state.

At one time or another in the testing program all of these types of extraneous force have been experienced. In the reporting of such forces, language has been used which should be useful and easily understood by lay personnel operating oil spill control equipment.

It is apparent that additional research should be carried on to investigate the forces in oil spills and it would be helpful if a universal nomenclature could be adopted so that all parties concerned will speak the same language in discussions of this phenomenon.

MECHANICAL BOOMS

Designs Available to the Testing Program

The mechanical booms available to industry at this time represent a wide variety of designs and materials.

For ready reference, we have classified each boom as a "curtain boom" or as a "fence boom".

"Curtain booms" include the following components:

A surface float which acts as a barrier on the surface and which supports a sub-surface curtain. The curtain is flexible and provides a barrier below the surface to a depth of as much as 18" or more. The flexible curtain may or may not be stabilized by weights or a cable to provide greater resistance to sub-surface currents.

"Fence booms" include:

A vertical "fence" or panel extending above the surface and below the surface, thus providing both freeboard above the surface and draft below.

Flotation which supports the "fence" in a vertical plane. The lower edge of the panel may be stabilized or strengthened by a cable or chain to increase structural integrity.

Each boom has its special characteristics, but each is directed at one common objective; namely, to counteract the forces which are exerted upon spilled oil and thereby to assist in the control and eventual clean-up of the spill. (See Exhibit 3 .)

In this project, 10 different models of boom were tested extensively under controlled conditions, and at the Louisiana spill (Appendix B.) two additional designs were observed in action.

"Curtain" booms tested included:

C-1 A flexible, plastic curtain extending 12" below surface, supported by a series of 6" cylindrical, closed cell, foamed plastic floats 10' long, having 3" of freeboard. Boom sections of various lengths are joined by stainless steel connector plates. One-quarter inch stainless steel cable runs the length of each section.

C-2 Same construction as above, with 8" curtain and 6" cylindrical floats 4' long.

C-3 Same construction as above, with 6" curtain and 4" float.

C-4 Same construction as above with 10" curtain and 6" float.

C-5 Same construction as above with 6" curtain and 4" float. Utility boom only. Not submitted for testing.

C-6 6" float with 12" curtain. Float chambers filled with polystyrene beads. Curtain stabilized with plastic keelsons sewed into bottom edge and with tension cable along bottom edge and attached to towing hitches.

C-7 6" foamed plastic floats 9' long enclosed in pocket of 1 piece nylon fabric, weighted with lead at bottom edges. Curtain has 9" draft. Float provides 4" of freeboard.

Light Fence Type booms

L-8 24" aluminum panels with rubber connecting panels and plastic foam buoyancy pads.

L-9 36" reinforced nylon fabric with plastic floats.

L-10 36" sheets of rubber-asbestos floated vertically by plastic buoyancy strips.

Heavy Fence Type booms

H-11 Flexible, reinforced fabric barrier supported by integral float chambers. 30" freeboard and 66" draft.

H-12 4' x 8' plywood supported by 55 gallon drums and connected by flexible rubber panels. Subsurface curtain hangs below lower edge of plywood to depths of 5'. Freeboard of 2'.

As soon as the existence of the project became known, manufacturers and suppliers of mechanical booms (and of many other types of equipment) were prompt and generous in offering their equipment for testing purposes.

The booms listed above were selected as representative of the various categories available. It was impossible to test all equipment offered because of time and budget limitations.

In addition to loaning equipment, manufacturers visited the project to instruct personnel in assembly, launching and maneuvering of the booms. This insured that equipment would be operated properly during testing procedures.

Throughout the project donors of equipment have been most cooperative in assisting with problems encountered in testing. In addition, they have welcomed comments and suggestions for improving their equipment. In many cases changes have already been adopted as a result of the testing program.

Functions of Mechanical Booms

There were no accepted criteria of boom performance at the time this project was initiated. Establishment of such criteria was a major objective of the project.

Before meaningful criteria could be adopted, project personnel acquired practical knowledge of boom operations by testing booms under a wide variety of conditions, developed standard testing procedures, and learned the functions which a boom should perform in a complete system of oil spill clean-up equipment.

Some of the principles of boom operation are summarized in the following paragraphs as a background to the evaluation criteria which were ultimately adopted. It is hoped that this summary will be valuable to assist prospective users in determining which boom might best suit the specific problems of the oil spill in which the boom will be used.

It became evident that surrounding and containing an oil spill with a boom is of very limited value unless the operation contributes to the successful removal of the oil from the water. Consequently in any consideration of booming technique the operator should plan his maneuvers to assist the skimming and other clean-up techniques which follow.

Most operational spills are of the limited variety. That is, a finite quantity of oil drops into the water, the source of the spill is emptied or blocked off and there is no continuing flow of oil to enter the area.

To be useful against a limited spill, a boom must be able to stop the spread of the oil until clean-up methods can be implemented.

Under calm air and water conditions a boom would have to surround the spill completely in order to accomplish this. If sufficient boom is available any of the curtain or fence booms would be effective.

In an unlimited spill the source of the oil continues to flow for a long period of time before it can be effectively stopped.

Under such conditions there is seldom enough boom at hand to contain the large volume of oil. Instead, the boom must be used to divert the flow of the oil effectively to the skimmers, suction nozzles or other equipment which is used to extract the oil from the water.

There are many alternative arrangements whereby booms may be used for this purpose. Some of them will be discussed in more detail in Appendix C. of this report.

When conditions of wind, wave and weather are present, the problem of containing a spill or of diverting its flow becomes more difficult, and a boom must be judged on its ability to conform to the wave profile, to withstand the stresses set up by wave action and wind action and to retain the design profile of its barrier. These qualities are essential if it is to function effectively. In addition to the operational characteristics described above, the boom must be graded for its ability to withstand extended exposure when stored or deployed in salt water for a long period of time.

Additionally, the ease with which the boom can be deployed, towed to the scene of a site, recovered, cleaned and stored for further use is very important.

In order to observe each test boom under controlled conditions, a Standard Testing Procedure was developed. This provided comparative data on each type of boom tested. The procedure included tow tests, diversion tests and careful analysis of problems incidental to rigging, mooring, deployment and recovery, cleaning and use of accessories.

In tow tests, a length of boom was towed from outriggers mounted on a work barge (See Exhibit 4.)

Oil was spilled into a loop of the boom during forward movement at the rate of 1K to 3K's. This tested the ability of the barrier to accumulate oil in the vee of the boom and to contain the oil in that position at varying speeds. Skimmers were operated in the vee of the boom to remove the oil thus contained. Sensitive marine speedometers were used to measure speeds relative to the surrounding water. As shown in Exhibit 4. , outriggers spanned a distance of 38'. Tow lines, 16' long, led from the outriggers to the end of the boom being towed. A length of boom being tested thus forms a catenary as shown on the exhibit.

With the boom moving across the water at relative speeds of up to 3 knots, generation of current, turbulence and eddies in front of the vee of the boom can be observed. It is also possible to measure the forward speed at which the turbulence begins to pull the contained oil underneath the boom. The action of the sides of the boom forward of the vee in diverting a surface film could be effectively observed and measured by using flotation material (chips, talc, sawdust, and shavings) in addition to oil. The effects of draft and freeboard were observed and measured. In the course of such testing it was evident that turbulence is the major cause of losing oil underneath the boom and that wave action is the major cause of losing oil over the top of the boom.

In these standard tow tests the formation of a smooth surfaced pool of calm water in the vee of the boom was apparent. In the configuration shown in Exhibit 4. the "pool" extended from 2' to 6' ahead of the vee of the boom. The forward edge of this pool was marked by a line of ripples similar to a tide-rip. Contained oil tends to stay in the "pool" area between the ripples and the boom. A section through the sub-surface structure of this oil pool would approximate that shown in Exhibit 5 .

The pool which can be maintained during towing at a speed of 1/2 to 1½ knots is sufficiently large and stable to provide a suitable area for the operation of a skimmer. In many of the tests a skimmer was towed behind the barge so that oil being diverted into the pool could be skimmed and pumped to the tank on the barge as fast as it was being spilled overboard from the barge.

To accomplish this operation without leakage of the oil under the boom, relative speed of the boom and the water must be slow enough to avoid generation of excessive turbulence. When the turbulence begins to cause leakage, forward speeds must be reduced.

Some booms will not contain oil at a relative speed of more than .5 knots. Others have contained oil at a relative speed of 1.5 knots. In general, the fence type booms contain oil at higher speeds than the curtain type booms. Booms can be used to encircle a spill and to move the spill by towing the boom, but this must be done very slowly at speeds of 1½ K or less. (See Exhibit 6.)

Observation of tow tests in waves up to 4' high led to a conclusion that in general the "fence" type booms with their high freeboard and rigid sub-surface structure showed promise of containing oil under some severity of wind and wave action. The "curtain" type barriers characterized by a low, rounded freeboard and a flexible sub-surface curtain were more suited to use in smooth water, in shallow water and under limited wave action conditions.

The tests described above indicated that outriggers provided effective maneuvering control of a flexible boom so that a pool of oil would form in the arc of the boom and effective skimming could be accomplished in the pool thus formed. The installation of tanks and pumping equipment made possible a complete clean-up system which could operate as a unit.

Towing a boom in the form of a funnel pointed toward a skimmer gave additional information about the capabilities of the booms. Exhibit 7. shows a typical tendency of a boom to bulge as the area between the two booms becomes squeezed into a narrow channel on its way to the skimmer.

Correction is needed because as soon as the boom starts to divert the oil more than twenty degrees from its normal path turbulence can be expected under the bottom of the boom and this will result in loss of oil.

To avoid this the type of rigging shown on Exhibit 7. can be used to minimize the tendency of the boom to bulge.

Tow tests also showed that too much tension on a boom reduces the boom's ability to flex in accordance with the wave profile, sometimes even to the point that portions of the boom can be completely submerged by a wave 3' or 4' high. This results in substantial loss of oil at the point where the boom is submerged.

"Funnel" tests showed that oil or other flotsam tended to hug one side of the funnel or the other depending on the direction of the controlling force which was moving the oil along the surface.

If the wind were the controlling factor and blew toward one side of the funnel, the oil would hug the boom on that side. Similarly, if the current proved to be the stronger factor, the oil was carried toward the down-current side of the funnel and the boom on the other side had little work to do. (See Exhibit 25.)

Single Boom Diversion Tests were developed in the later stages of the project. Tests indicated that a single boom could be used effectively to steer an oil spill away from a sensitive area or to divert its path to an area favorable for good skimming operations.

In small scale Diversion Tests it was noted that the "downwind" boom not only diverted the path of the oil but tended to keep the stream of oil compact and narrow, thus creating ideal conditions for the skimming operation which was to follow. (See Exhibit 8.)

The towing operations disclosed problems with the towing hitches and connectors which join one section to another. In one instance, wave action loosened connector bolts on one design of connector. These weaknesses were relayed to the manufacturers and steps have been taken by them to modify or re-design as necessary.

The connector plate supplied by one manufacturer was not compatible with a boom designed by another manufacturer. A new design was necessary whenever two different booms were joined end to end. It is strongly recommended that an industry committee be formed to work out a universal design for joining one boom to another of different make just as fire hoses are equipped with universal couplings.

There were no mechanical failures of any of the booms during the conduct of these standard tow tests in Portland Harbor. However, later operations in rough water conditions did produce structural failures such as ripped fabric, tangled rigging and broken components.

Rough handling, exposure to deterioration, high speed towing for deployment purposes and the twisting action of rough water may generate forces which are not apparent in the standard tests and which are more likely to cause physical damage to a boom.

Tow testing procedures indicated that the ability of a boom to hold together when strung across a 5 or 10 knot current may be an indication of the material strength of the boom but such ability is not an indication of the boom's effectiveness in containing spilled oil. Evaluation of the boom should depend primarily on its ability to contain oil and only secondarily on its brute strength.

The deployment of booms at the site of a spill has created some handling problems. The Maine Port Authority has successfully used a catamaran structure to store 1500' of curtain type boom on its deck. The boom can be arranged in a fanfold pattern when not in use. The catamaran thus serves as a carrier which can be towed rapidly to the source of a spill. The boom can be played out rapidly and effectively without danger to personnel or damage to the boom, just as fire hose is played out from the rear of a fire truck.

Deployment of any boom which is equipped with chains, cables or other loose lines can lead to tangles of the lines or cables with other parts of the boom. This has been a real problem on one of the "fence" designs and corrective action has been taken by the supplier.

In all instances where a boom was immersed in salt water for 30 days or more, the booms accumulated some quantities of marine growth on sub-surface sections. In permanent installations, such growth could accumulate to create problems and hazards. Measures should be taken to combat marine growth or to provide for an effective means for periodic removal of such growth.

Design of boom handling equipment should receive attention by the suppliers. Manpower is always at a premium, and any device which will take the muscle out of launching and recovery will be most welcome.

Evaluation Criteria

Considering all the operations factors listed above, evaluation criteria must be closely related to practical considerations if they are to be effective.

Furthermore there are so many qualities to be considered and environmental factors are so varied that evaluation must include judgments by qualified personnel as well as mathematical measurements of testing procedures.

In order to evaluate each boom, 19 characteristics of booms have been listed in groups as follows:

Performance under Calm Water conditions

Containment The ability to restrain a spill against the forces which seek to spread the spill over a greater area

Compaction The ability to gather the oil inwardly so that it covers less area and the slick becomes thicker to assist the skimming efficiency

Towing The ability to move the spill across the surface of the ocean in a direction counter to that urged by wind and current forces

Diversion The ability to divert the flow of a stream of oil counter to the influence of wind and current and to bring about a change in the flow of a stream emanating from an oil spill

Protection The ability to function as an inert barrier in the path of an oil slick which is threatening a sensitive shoreline. (Recreation area or wild-life refuge.)

Ability of the boom to perform the above functions in the presence of severe wind or wave conditions, as follows:

Ability of the boom to flex and conform to wave profile

Stability of the boom in holding its preferred position in the presence of "knockdown" wind gusts or squalls

Structural integrity when subjected to the strains imposed by heavy seas and strong winds

Dependence on critical rigging or mooring operations or special handling techniques

Design Convenience Factors

Ease of assembly when received from the manufacturer

Ease of launching from boat or dock

Performance while being towed to site of spill

Ease of coupling one section of boom to another

Ability to make a leakproof attachment to a dock or boat

Compatibility with other booms or with other oil spill equipment

Ease of hauling onto boat or dock for cleaning, storage or transport

Cleaning of oil or marine growth

Shelf Life Factors

Shelf life on-shore during periods of non-use

Deterioration when deployed in the water for extended periods of time in stand-by status

Project personnel made independent judgments of each boom on the qualities noted above. Performance on each item was graded from 1 to 10, and bonus points were awarded for those factors which were considered to be the more important.

Five "curtain" type booms were graded on the system described above, and three "light fence" type booms and two "heavy fence" designs.

On the basis of total points scored by each boom, the light fence booms scored appreciably ahead of the curtain type booms. The heavy fence booms, graded on the basis of their performance at the Louisiana spill, scored better than the curtain type booms but by a more narrow margin.

Results of the grading are summarized in the Tables on the following pages.

COMPARATIVE GRADES OF 10 MECHANICAL BOOM DESIGNS

GRADED BY	CURTAIN BOOMS					LIGHT FENCE BOOMS			HEAVY FENCE BOOMS	
	C-1	C-2	C-4	C-6	C-7	L-8	L-9	L-10	H-11	H-12
Total Points	536	570	507	524	469	513	664	711	570	672
Relative Rank	5	4	8	6	9	7	3	1	4	2

NOTE: Heavy Fence Booms graded only on performance in Louisiana spill.

Booms C-2 and H-11 tied for fourth place in standings.

AVERAGE SCORES BY GROUPS - Countering Oil Spill Forces

	Curtain	Light Fence	Heavy Fence	Best Group	Remarks
Class 1. Ability to Counter the Forces in an Oil Slick in Smooth Water Conditions					
a. Containment	7.2	13.3	18.5	Heavy Fence	Heavy Fence group has higher freeboard and greater draft.
b. Compaction	5.9	11.6	5.0	Light Fence	Easiest to maneuver. Curtain booms with short floats are easier to handle in the water or on land than those with long floats.
c. Towing a pool of oil	7.5	13.2	12.0	Light Fence	Fence structure maintains vertical profile.
d. Diversion	9.9	17.2	12.0	Light Fence	Mobility, maintains vertical profile.
e. Protection	6.1	12.0	13.5	Heavy Fence	Most freeboard and draft.

AVERAGE SCORES BY GROUPS - Rough Water Performance

	Curtain	Light Fence	Heavy Fence	Best Group	Remarks
<u>Class 2.</u> Ability to Control Forces in Rough Water Conditions					
a. Conformity to Wave Profiles	9.3	16.0	17.0	Heavy Fence	Both fence types are far ahead on this item.
b. Stability against knockdown	7.1	11.9	14.5	Heavy Fence	Heavy weight is a stabilizing factor.
c. Structural integrity	11.5	12.3	14.5	Heavy Fence	Any design can be wrecked if not moored properly.
d. Dependence on Critical Rigging operations	7.4	9.6	11.5	Heavy Fence	Basic strength of Heavy Fence types makes them less critical.

AVERAGE SCORES BY GROUPS - Design Factors Affecting Deployment

		Curtain	Light Fence	Heavy Fence	Best Group	Remarks
Class 3. Design Factors Affecting:						
A.	Assembly	11.9	10.7	2.5	Curtain	Light weight and portability were generally good in the Curtain group, while power equipment is needed for assembly of Heavy Fence group.
B.	Launching	12.3	11.6	11.0	Curtain	Weight is controlling factor.
C.	Towing to site of spill	11.2	9.7	12.0	Heavy Fence	Proper rigging of towing bridle is critical on Light Fence type.
D.	Coupling	11.2	9.5	10.5	Curtain	All groups need better hitches.
E.	Attachment	6.9	7.7	9.0	Heavy Fence	All groups scored poorly on this factor.
F.	Compatibility	7.9	8.6	9.0	Heavy Fence	This factor needs much more attention.
G.	Hauling	12.5	9.5	8.0	Curtain	Light weight scores heavily for Curtain Booms. Power equipment needed on Heavy Fences.
H.	Cleaning	6.1	6.0	3.0	Curtain	Hand labor needed on all types.

AVERAGE SCORES BY GROUPS - Shelf Life Factors

	Curtain	Light Fence	Heavy Fence	Best Group	Remarks
<u>Class 4</u>.					
On Shore Storage	10.4	8.0	3.0	Curtain	Light weight and easy to store between periods of use.
Water Storage	13.0	12.4	14.5	Heavy Fence	Generally good, but very light materials on Curtain group are fragile under rough handling.

Conclusions and Recommendations

Conclusions

1. The use of a boom to control the movement of an oil slick can accomplish these tasks:

    a. If complete encirclement is possible, the boom can

    1) Prevent further spread of the slick, and

    2) It can contain a large amount of oil - up to at least 2" of film thickness - as long as wind and wave permit.

    b. As a barrier across the path of a spill, a boom can

    1) Delay passage of the slick until depth of oil pool against the arc of the boom approaches two-thirds of the draft of the boom, or

    2) Until current and turbulence pull oil under the boom.

    c. Used as a sweep or trawl, the boom can

    1) Gather pools of surface oil in the arc of the boom so that skimming operations can be effective in those areas.

    2) Compact widely scattered puddles of oil or very thin films so that the efficiency of skimming can be improved.

    3) Tow or pull limited areas of slick from one location to another to avoid sensitive areas or to reach fixed oil-removal installations.

    d. Used as a means of guiding the flow of an oil slick, the boom can

    1) Divert the flow of a spill by as much as 20° from its natural path.

    2) Lead a slick to the area where skimmer equipment is operating.

    3) Limit the spread of a flowing spill in the area near the source.

2. For use in rough water, a minimum of 12" of freeboard is essential to reduce over-flow by surface waves and wind-driven spray.

3. Present designs can be effective when operated by trained personnel, but continued development of accessories and easier handling techniques are needed.

4. The overall evaluation of various styles of mechanical booms suggests that

   a. The curtain booms can be effective in shallow water and calm wind and wave conditions. As such, they offer very good cost effectiveness in protected waters.

   b. The light fence types offer the greatest protection and versatility for most situations, though their effectiveness may be very limited in shallow waters. (Less than 2 feet.)

   c. The heavy fence types are handicapped by heavy weight, and the need for mechanized handling equipment but their extra freeboard and stability can be very valuable in rough water conditions.

Recommendations

The following items should be considered by any supplier or manufacturers of boom equipment:

1. Improve the part that the boom can play in a complete clean-up system by

   a. Making it compatible with other equipment.

   b. Making it compatible with other booms.

   c. Increase the ease of launching and recovery from a work boat or dock.

   d. Design the boom to assist the clean-up operation - whether by skimmer, chemical or other device.

2. Improve its ability to exert more force against an oil spill.

   a. Consider the addition of air or water jets to augment its abilities as an inert barrier.

   b. Consider the aerodynamic possibilities of the freeboard structure as an assist in rough water.

3. Explore the use of multiple booms, with a secondary structure to act as

   a. A channel to pick up small patches of oil which may get past the primary structure.

   b. An auxiliary structure to act as a wave damper in choppy water.

4. Designers should explore the use of a material to limit the accumulation of marine growth on a boom, and should provide a method for cleaning such growth from a boom.

5. More attention needed on leak-proof fastening of booms to docks, boats and skimmers.

AIR BARRIERS

Designs Available to the Testing Program

When this project was activated the Maine Port Authority expressed a definite interest in using an air barrier at one or more critical locations in Portland Harbor.

Correspondence was initiated with two manufacturers of air barrier equipment, but it was evident that each one preferred to engineer a custom design for a specific application at a designated location rather than to supply equipment for a testing and evaluation program. This plan did not meet the requirements of the project, which involved tests at several locations in the Portland Harbor area.

Efforts to obtain an air barrier for testing purposes disclosed that Maine sardine fishermen have for years used air barriers to pen sardines inside a cove while netting takes place.

1600' of such barrier was acquired for the project. A portion of the length was of 3/4" I.D. flexible p.v.c. hose and the balance was of 1" I.D. hose.

With this substitute equipment the tests described later were performed. Those tests demonstrated many of the characteristics of air barriers, or "bubble curtains" as they are sometimes called.

In November, 1969, one manufacturer offered an air barrier of 1" I.D. aluminum pipe for the testing program.

The offer was most welcome and arrangements were made to conduct tests in waters up to 50' deep adjacent the former Navy refueling docks on Long Island in Casco Bay, Maine. Personnel who designed the barrier accompanied the equipment to Portland to assist in a three day testing program under a wide variety of surface conditions. During theses tests attempts were made to take underwater photos of the pattern set up by the bubble barrier but scuba divers were unable to cope with the combination of murky water and the strong vertical currents set up by the equipment being tested. Surface conditions throughout the tests were recorded on colored slides.

Tests and Evaluations

The series of tests was directed toward the following objectives:

1. To determine the problems inherent in assembling, launching and operating an air barrier in Maine waters.

2. To determine the basic characteristics of the air barrier curtain.

3. To determine the air barrier's basic ability to counteract the forces which affect an oil spill.

    a. When working from a permanent installation on the bottom.

    b. When working from a supported position at a selected depth.

    c. When used as a highly mobile unit for sweeping, collecting or diverting an oil spill or other flotsam.

Note: In measuring the forces generated by the air barrier curtain marine speedometers were used to establish that the air bubbles generate surface currents floating away from the "Z" line (the Z line is shown in Exhibit 9 .) The surface currents are generally at right angles to the Z line. Using the same technique it was found that very little horizontal current is present at depths of 6" and 18" below the surface except within 2' or 3' of the Z line. (See Exhibit 10.) However, there is also a vertical current of some magnitude generated by the rising air bubbles. The potential of this phenomenon has not been fully explored.

Tests of Maine Port Authority Air Barrier (Floating and Fixed) at Test Area

Maine Port Authority's Air Barrier, about 200' of 1" flexible hose and about 400' of 3/4" flexible hose, with small holes (Approximately 1/32" diameter) spaced 18" apart, was used.

The first test with the air barrier was performed by placing the 200' of 1" air barrier hose across the outboard end of slips 3 and 4 at the testing site. Air was supplied from a 125 cfm air compressor operating at 100 psi. When air was first applied to the air barrier hose it required less than two minutes for the air to displace the water in the hose for the full 200' length. The surface boil appeared at the compressor end immediately and extended rapidly for the full 200' across the slips.

The turbulence created by the air barrier varied from 6' to 8' wide and consisted of a surface current moving outward from the center line (the Z line) of the barrier. In this surface current, pieces of seaweed and flotsam were brought to the surface by the upward motion of the air and water and carried outward by the water currents created. Near the outward edge of the surface current these objects dropped down to lower depths.

These first observations indicated that an air barrier creates sub-surface vertical currents due to the rising air. Surface currents extend outward from the center line of the barrier as a result of the upward vertical current.

A test series was performed to determine the action of the air barrier on partially submerged objects and the effect the air barrier would have on tidal or current flows. The 400' of 3/4" hose was coupled to the original 200' of 1" hose and layed on the bottom of the slips as shown in figure A.B. 1. To study the effect on submerged objects, 16 ounce cans filled with water were suspended from small floats. This arrangement provided a reasonably large suspended object and a condition of nearly neutral buoyancy. With the air barrier on, it was observed that the cans in slip #3 collected at the sharp vee and were carried through the air barrier by the outgoing tide. The cans in slip #4 escaped from the slip into the open passage and moved out at an accelerated rate. This indicated that the air barrier had some effect 3' below the surface and to some extent diverted the outgoing tide to the open area. This testing was reported after removing the sharp vee and although the cans in slip #3 drifted toward the barrier none of them penetrated through the vertical currents it generated.

Additional tests were conducted using 200' of the 1" hose stretched across slip #3 and halfway across slip #4. The cans which formerly were suspended 3' below the surface, were changed to one group 3' below the surface, one group 7' below the surface and the third group 12' below the surface. These tests, which were conducted on both incoming and outgoing tides, showed that the air barrier diverted the tidal flow to the extent that no cans crossed the air barrier and most of them were carried by the current to the opening in slip #4. It was also observed that the rate of tidal flow through the narrow opening in slip #4 was more than twice the normal rate of tidal flow in and out of the slips when the air barrier was not running. These tests clearly indicated that an air barrier can be used to partially divert a tidal flow or current having a velocity of 1½ K or less. (Exhibit 11.)

Tests on the surface effect of air barriers using talc showed that during a period of wind velocity of 15 to 18 knots that talc blown across the surface came to a stop as soon as it met the outgoing surface current some 4 to 6' from the center line of the air barrier. When there was a sharp vee in the air barrier some talc would escape through the irregular surface pattern at the vee. When the vee was removed and replaced by a gentle curve the loss of talc was stopped.

During these tests it was also observed that although the water surface appeared to be relatively clean, traces of oil and other flotsam were collected at the edge of the air barrier current after about ten minutes of operation. The restraining effect of the current was clearly demonstrated when a styrofoam coffee cup was blown toward the barrier and was stopped by the surface current created by the air barrier. This same result occurred using styrofoam balls and rolls and various floats and buoys. In all tests it was apparent that it was the outward flowing surface current which acted as the barrier, and not the height of the boil. Therefore air barrier design should be based on creating the maximum upward vertical current by the rising air bubbles, as it is this vertical current which becomes the outward flowing surface current.

To determine the vertical currents and resulting out-flowing surface currents at various air barrier depths and air pressures, the air barrier was secured to a line stretched across slip 3 just below Mean Low Water. Tests were run at each foot rise of the tide.

Operations at less than 4' depth resulted in a poor surface current pattern. This was caused by the wide (18") spacing between the air holes which resulted in a broken surface pattern. As the depth increased from 4' to 7 or 8', the outward flowing surface increased. For depths greater than 8', up to the maximum of 16' observed during these tests, the outward flowing surface currents were measured at .7 K close to the Z line and a .2 K at 20' from the Z line.

For each different depth of air barrier, observations were made for 40 psi, 70 psi and 100 psi air pressures. At 40 psi there was not a sufficient amount of air discharged to create a steady and uninterrupted outward flowing surface current. Both the 70 psi and 100 psi operating pressures created the desired outward flowing surface current. The area effected by the current increased from 3' to 4' from the air barrier center line at 70 psi to 6'-8' at 100 psi.

Several tests were made to determine the effectiveness of an air barrier used to sweep an area. For these tests the air barrier was suspended at various depths for 3' to 8' from floats. About 40' of air barrier was stretched between the outriggers of the barge. A 25 cfm compressor on the barge supplied the air at 75 psi. When the barge was towed at any speed over 2 knots the outward surface current created by the air barrier was broken up as a result of the forward motion. Talc or other floating objects were able to pass quite freely through the barrier. During these tests it was observed that the air bubbles rising from the air hose appeared to be much larger and fewer in number than were observed when the air barrier was stationary.

Another series of tests was conducted using 80' of air barrier suspended at 5' and at 10' below the surface. During this series of tests the air was supplied from the shore based 125 cfm air compressor at 100 psi. The free end of the air barrier was towed to sweep a circular area around the end of the pier. Good sweeping action was obtained, particularly near the pier where the barrier was travelling at slow speed. Again it was observed that there was a tendency for the air to form large bubbles as the air barrier moved through the water, and that fewer large bubbles create less outward flowing surface current than a larger number of small bubbles.

To determine the bubble patterns for different size holes at different air pressures and depths, a series of holes, spaced one foot apart, was drilled in a 12' length of 1" I.D. aluminum pipe. The holes were drilled with even numbered drills, from #60 (.040") to #40 (.098").

The test pipe was suspended from the outriggers across the end of the barge, and the air was supplied by a 25 cfm air compressor mounted on the barge.

These tests showed that the bubbles of air escaping from the largest hole (#40 drill - .098") were no larger than the bubbles escaping from the smallest hole (#60 drill - .040"). However, because more air was escaping from the largest hole than the smallest hole (approximately 6 times the volume, based on the hole areas), the outward flowing surface currents above the largest hole were significantly greater than the currents above the smallest hole. During the series of tests the depth of the air barrier was varied from 3' to 10' and the air pressure was varied from 5 psi to 10 psi. For each combination the surface current pattern over the largest hole was visibly stronger than the pattern over the smallest hole.

During these tests it was again noted that when the boom was stationary or moving slowly the pattern of small bubbles remained, but when the barge was moved more rapidly larger bubbles were formed.

Air bubbles rising from water do not assume an aerodynamic shape and travel in a straight vertical path unless lateral current is present. The shape of an air bubble is generally circular, and the bubble moves from side to side as it rises. The water passing between two adjacent rising bubbles forces them apart, so that the pattern formed by the air bubbles coming from a single hole is an inverted cone.

This test of Commercial Air Barrier equipment was conducted on December 13, 1969 at King Resources Long Island Pier in Casco Bay, with a 10 to 15K wind.

The barrier equipment consisted of five 20' lengths of 1" I.D. aluminum pipe drilled every 6" with a 1/16" hole. The sections were coupled together with a semi-flexible compression type coupler.

The barrier was initially placed in 40' of water alongside the pier and was coupled to a 600 cfm compressor with 50' of 2" I.D. rubber hose. The operating pressure at the compressor was 45 psi. When the system was activated a good boil appeared on the surface in 1-1½ minutes and within 3 minutes the surface current was established the entire length of the barrier. The surface boil was apparent but of more importance was the surface current extending 15 to 18' on either side of the Z line. This action completely knocked down the 1' chop that was on the water. The outflow of the current was very apparent and its affect on the waves was quite spectacular. Several floating objects and standard oil substitutes were placed in the water up-wind of the barrier and not one of them approached within 15' of the Z line. The floats that were attached to the barrier to spot its location were also driven away from the Z line as far as their lines would allow them to go and the current at the base of these floats was quite apparent. The work boat was sent into this current using its engine to hold a fixed location and currents of 1½ to 2K were recorded close to the Z line.

During this test divers were attempting to take pictures of the bubble pattern as it left the pipe, using 1500W waterproof lights. They were not very successful for several reasons. The water itself was not too clear, the bottom was being stirred up by the action of the barrier and it was reported by the divers that the turbulence of the water made it very difficult for them to maintain their position while photographing.

For these reasons the barrier was raised to 20' of depth to eliminate the disturbance of the bottom. There was no apparent change in the surface pattern of the barrier. The ascending bubbles did not appear to change shape or size due to the change in depth. The current measurements made by the work boat did not change significantly and floating objects were held at the same distance as before.

This barrier from all indications was very successful and if it is used as a device to protect sensitive areas in a fixed location it could be effective. Further studies of air barrier applications should be undertaken to determine its adaptability as a diverting boom, a sweeping boom and a mobile containment boom.

Air holes in an air barrier pipe have a tendency to become plugged (this was true of both types of equipment tested.) This spoils the pattern of the barrier and reduces its efficiency.

Test operations indicated that:

a. Frequent shut-down of the system tends to pull foreign matter and marine growth into the air holes from the surrounding water.

b. The suspended barrier pipe (6' above the bottom) was less susceptible to plugging than the pipe laying on the bottom.

c. The problem can be minimized by maintaining an air flow at low pressure as a stand-by procedure, and then increasing the pressure to the range of maximum effect when need arises.

d. As an alternate to c. above fresh water can be pumped through the air hose during stand-by periods. A low pressure water flow will keep the air holes clear. When barrier operation is required, the water is turned off and air pressure is applied.

Conclusions and Recommendations

Tests described above led to the following conclusions:

1. Air Barriers hold real promise for fixed installations across slips and parallel to unloading docks, for

   a. Continuous stand-by operation at reduced air pressures should keep the hose ready for instant use, with maximum air pressure to be used only in emergencies.

   b. The Air Barrier generates its strongest horizontal forces at or near the surface of the water. Vertical forces are also present, but their effect on oil spills needs additional research.

   c. The sub-surface air curtain can partially divert sub-surface tidal currents of low velocity.

   d. An air barrier can be almost as mobile as a mechanical barrier. Compressors, buoys and other accessories for operating an air barrier can be ship-mounted without undue difficulty.

   e. The Air Barrier's ability to contain or divert oil in rough water has been tested by the manufacturer but results have not yet been published.

2. Some models should be sufficiently versatile to operate in several different applications.

   We realize fully that a general purpose model might entail a compromise with some engineering refinements which could be realized if the barrier were engineered for a specific task.

3. The Air Barrier may perform effectively in rough water conditions where the full force of surface waves and wind would not be exerted against the air supply pipe suspended sub-surface.

4. An Air Barrier used to surround a ship at a pier or at a single-point-mooring has some potential economic advantages as follows:

   a. Moderate installation costs

   b. Minimum manpower to activate and monitor its performance

   c. Will not limit the access of supply and work boats to the tanker

   d. Not susceptible to accumulation of ice in freezing weather

<u>Recommendations for Further Testing and Development</u>

1. The potential for permanent installations should be researched in more detail because of

   a. Possibility of low installation costs and low upkeep

   b. Possibility of using an air source which could be inter-changeable with other productive work when the air barrier is not required

   c. The barrier can be quickly and effectively activated by one man when needed

2. The potential of a mobile air barrier should be explored.

3. Rough water performance needs further research and demonstration.

SKIMMERS

The Urgent Need for Skimming Capacity

The second Phase progress report on this Project, (October 1969) included the following statement: "the biggest problem in developing a viable system (for oil spill clean-up) is that of designing improved skimmers....."

That statement was borne out at the beginning of the Louisiana oil spill (See Appendix B.) when the need for massive skimming capacity was so imperative. There simply were no high volume skimmers available from the equipment industry in this country. Best estimates at that time indicated that skimming capacity would need a total through-put volume of 75,000 barrels of liquid per day (@ 42 gal. per bbl) at an oil/water ratio of 10% (10% oil to 90% water) if they were to contain the expected spill.

Fortunately, this project had tested one design of skimmer which indicated that the circular weir principle of skimming had real potential for large volume operations. In addition, this principle had the virtue of simplicity and could readily be designed into a large volume skimming nozzle. Also, the resulting design could be built rapidly by most welding shops.

The design (See Exhibit 12.) proved to have a through-put of 420 GPM using a 4" Impeller Pump driven by a diesel engine. 420 GPM is equal to 10 bbls (a standard oil barrel per minute of 600 barrels per hour or 14,400 barrels per 24 hour day. Six of these skimmers (referred to as the AK skimmer) could provide a through-put of over 80,000 bbls per 24 hour day, if each could be used at full capacity.

Twenty of the design were built and deployed on various skimmer boats and barges. (Exhibit 13.) They were heavy, crude and required power lift equipment to move them on or off the boats, but they performed reasonably well.

Later in the operation, 10 additional circular weir skimmers were built and added to the skimmer fleet. Their capacity was slightly less than the AK design.

While these makeshift products were successful in a substantial portion of the skimming at the Louisiana spill, they are probably obsolescent already, for a great deal of development work is going forward and improved designs will certainly be available in the near future.

State of the Skimming Art

The problem of removing spilled oil has sparked the imagination of many designers. By the summer of 1969 their efforts seemed to fall into 5 approaches to the skimming problem. During the Project, 22 skimmers were identified in 5 design groups as listed on Exhibit 14 . Five of these were tested in the Project. Seven others were inspected, on display or in some form of demonstration. Information on nine others was available in the form of literature and reports.

1. The "separating" skimmers. (8)

   This group included many variations of the adhesion principle, wherein oil would preferentially wet an endless belt or a rotating drum which operated partly submerged in the oil.

2. The "blotter" skimmers. (3)

   Several designers placed absorbent material in net sacks which, in turn, could be dropped into an oil spill to soak up the oil. When loaded to capacity, the sacks could be withdrawn and either discarded or wrung out and used again.

3. The "suction" nozzles. (3)

   Suction hose nozzles operated from vacuum trucks have been widely used when the trucks could be placed near a spill.

   Some are rigid, like a household vacuum cleaner nozzle, and others are sufficiently flexible to conform to some degree of wave action.

4. The "separating column" skimmers. (3)

   These are barge - or boat-mounted devices for drawing oil and water into an open-bottom hold or sump on board a boat and allowing the oil to rise to the top where it can be removed by suction, by a weir or by a standpipe.

5. The "floating weir" skimmers. (4)

These designs support a weir (either a straight line weir or a circular weir) so that the intake (the top of the weir) is floated below the surface of the area to be skimmed. The weir is positioned as close to the underface of the oil slick as possible, and the oil and water together flow across the weir and into a sump. A suction pump transfers the oil/water mix to another tank for further separation.

(Note: In addition to the evaluation of 21 skimmers listed above, project personnel developed and tested an "articulated" skimmer which is described in more detail later in this section.)

This project tested two commercial floating weir skimmers and one experimental flexible suction nozzle skimmer. Two endless belt designs were inspected, neither of which was operating. A prototype of a floating skimmer with four independently mounted weirs was also inspected and its operation checked with other observers.

The skimmers in 1,2,3 and 4 above have been designed to accomplish 100% separation of oil from water at the site of the spill. With present technology this group of "selective" skimmers is characterized by generally low volume capacities and loss of efficiency in rough water conditions. (The above statement based on reports from equipment manufacturers in addition to observations made on this project.)

It is undoubtedly desirable to work toward a high volume skimmer which can separate oil and water efficiently at the point of skimming but the achievement of this objective may be some years away.

Consequently, a worthwhile short-term objective is that of pumping a high volume of oil/water mix, always understanding that every attempt should be made to keep the oil/water ratio as high as possible. "Skim first and separate later."

The circular weir skimmer with adjustable rim which was tested in many of our experimental spills has given firm indications that its basic design in a larger size might provide an immediate answer to this "interim" objective. In smooth water tests it has performed with high efficiency while pumping a thick oil spill. In test spills of small volume such pumping action thins the film very quickly. As a result the clean-up of a 100 gallon oil spill results in pumping a high ratio of oil/water mix for only 5 or 6 minutes during which time 75% of the volume of oil is usually removed.

Clean-up of the remaining 25% of the spill requires 40 to 50 minutes during which time the skimmer is working at low efficiency. During the final clean-up, some device must be employed to move the skimmer to the remaining polluted areas or the remaining pools of oil must be urged toward the skimmer by moving the containment boom. (See Exhibit 6.)

There are other approaches to skimmer design which may prove to have potential in meeting the interim objective as well as the final objective as described earlier in this section. However, the circular weir skimmer used in this project performed so well in rough water (waves to 8' - 35 K winds) that a larger embodiment of that design should provide a major increase in skimming capacity, and multiple units could be effective in dealing with the volumes of massive spills.

Design Problems of "Selective Skimming"

Referring again to the "selective" skimmers described in 1,2,3 and 4 above, emphasis on complete separation at the point of removal creates more problems than it solves. In this project it has been apparent that inclusion of the separation function slows down the removal operation to such an extent that most of these "selective" skimmers are characterized by very low rates of production.

For example, the 3 "Separating Column" skimmers depend on the tendency of oil to rise to the surface for their ability to separate oil from water at the point of removal.

As pointed out previously, oil does not travel to the surface instantly. Its rate of rise depends on the specific gravity of the oil, size of droplets or globules, temperature of sea water and other factors.

Rate of rise seems to have been overlooked by designers of skimming equipment in some cases, and the time required for that rise to the surface may become a limiting factor on the rate of through-put for the equipment.

The inability to handle large volumes of oil, for whatever reason, restricts a skimmer's attractiveness in combating large oil spills simply because of the restrictions on volume. However, the separating skimmers do have application to small spills where volume does not go beyond a few barrels.

Furthermore, the complexity of the separating mechanism creates operational problems as soon as operation is attempted in choppy waves or in any situation where a heavy ground swell is apparent.

It has also been apparent that any collection device fixed rigidly to a boat or barge has limited ability to conform to wave action.

In such cases, wave action which causes the vessel to rise and fall even slightly may negate all the careful setting of the skimmer at the proper level for efficient operation. Whatever device is used for the adjustment of the weir or intake nozzle, the plunging of a barge or vessel can lift the skimmer completely out of the water or submerge it for several feet below its optimum operating position unless the skimming element itself is independently floated.

The endless belt design, of course, is a possible exception to the above statement because the belt could be arranged to travel through a wide range of wave heights. Even so, the efficiency of pick-up on the belt itself might be reduced appreciably due to the variation in the speed with which any point on the belt would travel through the relatively thin section of the oil slick.

Effect of Thick and Thin Slicks

All tests to date have indicated that it is far easier to pump or skim effectively in a thick film of oil than in a thin film. (See Exhibit 16.)

Most skimmers can pump oil effectively from a deep pool of oil or from an oil slick 2" or more in thickness.

In considering the design of skimmers it should be kept in mind that an oil spill is not a static situation. Left to itself the slick continually changes size and shape while the physical and chemical actions such as evaporation, spread effect and other phenomena exert their influence.

This results in some spills being very thick near the source, but rapidly becoming thin at some distance from the source or after enough time goes by.

The high-volume skimmer used for attacking the thick spill is much less efficient when working on a widespread slick that has become very thin. One obvious approach to this situation is to use booms to compact the slick. However, such maneuvers take time which may not be available. Therefore, there seems to be an opportunity to develop a new skimmer design which can travel fast enough to skim a very thin surface film at a speed of 10 to 12 knots or more and to sweep a relatively wide path in the process.

There are reports of a new design intended to sweep 120 acres per hour. This could be accomplished by a sweep 110' wide travelling at a speed of approximately 10 miles per hour. A wider sweep would permit slower forward speeds. Any combination which would skim 120 acres per hour would be most welcome in dealing with the widespread "iridescent" slick which is frequently associated with a large spill.

It is evident, of course, that a selective skimmer, producing 100% oil at 100 gallons per minute would equal the production of a non-selective skimmer producing 1,000 gallons of oil/water mix at 10% efficiency. However, in a very thin spill a selective skimmer would have to cover a lot of area to contact 100 gallons of oil with its belt or drum. In a thick spill, the problem would be easier for either type of skimmer. Consequently, both approaches should be considered in further development efforts.

Design of an Articulated Skimmer (Exhibit 15 .)

At the start of this project the need for a successful off-shore skimmer was apparent. The contract authorized use of funds to construct a working model of any design which showed promise of working successfully in rough water (waves to 10') and high winds (to 35 Knots.)

Personnel employed on this project developed an initial concept of an "articulated" skimmer, composed of 2 or more sections hinged together but independently buoyant, so that each section could ride up or down the front or back of an ocean swell without effecting adversely the operation of adjoining sections.

The "articulated" feature was tested successfully in waves of 4' in height at several times during the project.

In addition to its ability to conform to wave profiles, the skimmer was designed toward these objectives:

High volume through-put capacity - 500 gallons per minute, or more, of liquid. (Either oil or oil/water mix)

Readily portable by boat or aircraft.

Trouble free operation in rough water.

Intake adjustable to thickness of slick.

Compatible with booms.

Capable of working in groups of three or more at a time.

Initial construction and modification of the working model was completed in March of 1970 and tested in one small, experimental oil spill.

The skimmer was tested before that date without oil on several occasions. In its experimental size it has demonstrated a through-put capacity of over 250 gallons per minute. It has maintained a uniform thickness of skimming depth at speeds up to 2 knots while running over waves of 1 to 2 feet in height. The design may be worth additional development.

In the final test the skimmer was used to pick up a small oil spill. The down-wind end of a 50' diversion boom was attached to one side of the "sluice" or entrance to the skimmer. The up-wind end of the boom was anchored. Five gallons of crude oil were spilled at the up-wind end of the diversion boom. The resultant slick was eventually 50' long, (from the point of spill to the point of entry into the skimmer.) The spill was urged toward the skimmer by a 10K breeze, and the slick was held against the diversion boom as expected by the force of the wind, being no more than 2' wide at any point during its journey. (Exhibit 8 .)

As the floating oil entered the skimmer, the surface slick and some sub-surface water passed over the entering edge of the skimming blade which was set at a depth of 2" below the surface. (Depth is adjustable.)

The oil/water mix then passed over the two articulating hinges to a point where the paddle wheel pump elevated the mix into a sump tank.

The sump was continually drained by suction pumps which moved the oil/water mix into a floating tank where primary separation of oil and water could take place.

The 5 gallon spill was cleaned up completely in less than 2 minutes after the slick reached the skimmer.

The skimmer has been described in detail on Invention Disclosure Forms which have been forwarded to the Contract Officer as required.

Pumps and Accessory Equipment

Several of the skimmers studied in this project depend on standard commercial pumps and hoses to move the oil/water mix away from the point of skimming and into the next tank or conduit in the system.

When such skimmers are floated independently of their pumps there are two potential problems which should be considered in future design of skimmers.

1. The connecting hose must be flexible

   a. To allow the skimmer to float on the surface without impeding the skimmers ability to match the contour of the waves, and

   b. To pass over, under or around any booms or other equipment which may be located close to the skimmer.

2. The hydraulic head between skimmer and pump must be kept as low as possible to minimize priming problems and to insure maximum efficiency of the pumping.

Self-priming pumps are desirable at initial start-up of operations, but the ability to pick up prime following periods of temporary loss of prime is essential. In any sort of rough water operation, a skimmer will surely encounter wave action which temporarily starves the intake, and the pump must be able to pick up its prime and keep going without the necessity for shutting down and repriming manually.

From the discussion above, it is evident that a selective skimmer mounted on a boat or barge with all its connecting equipment combined into one system of containment, removal and some storage capacity, is in itself a complete system.

When a skimmer is limited to the removal function and must be combined with other equipment from other designers, compatibility with that other equipment is very important. Designers should make every attempt to insure that their skimmers are indeed able to function as an effective part of a complete system.

Conclusions and Recommendations

Conclusions

1. Improved skimmer designs are needed:

   a. For rough water operations

b. For high-speed pick-up of thin oil slicks spread over wide areas.

2. For massive oil spills, a through-put of 500 gpm or more is needed.

3. Most versatile design at time of this report seems to be the circular sump with a fixed or adjustable weir.

4. The endless belt "separating" skimmers have good potential for small spills in protected waters.

5. Dependable pumps, motors and accessories are essential for good skimming operations.

6. The skimming process, by itself, will not generate a surface flow of oil for any great distance. 6' to 10' seems to be the maximum at present.

7. The skimmers must go to the oil, or the oil must be brought to the skimmers.

8. Skimmers should have a high degree of compatibility with all other units in the system.

Recommendations

1. The development of improved skimmer designs should be accelerated until there is high volume capacity at strategic points near all petroleum centers.

2. One major objective is the skimming of massive spills in rough water conditions.

3. Another objective is the skimming of very thin slicks spread over wide areas.

4. Optimum performance toward these two separate objectives may require the use of dis-similar skimming principles.

RECLAMATION AND DISPOSAL EQUIPMENT

Oil/Water Ratios and the Recovery System

Whenever an oil spill is skimmed from the ocean, some system must be provided to store, transport and dispose of the oil involved.

Hopefully the ultimate destination of the skimmed oil will be a refinery which can process the recovered oil and reclaim it to the point that it can be turned back into industry and its economic value can be realized.

Somewhere between the ocean and the refinery, water must be separated from the oil to make the oil acceptable to the refinery process.

If an efficient "separating" skimmer is used initially, the separating is accomplished at the site of the spill. From that point on nothing but the oil need be put through the storage, transport and disposal system.

If a separating skimmer produces a mix of 90% oil to 10% water the liquid quantities downstream of the skimmer will be far smaller than with an ratio of 10% oil/90% water. Under those circumstances the problem of transporting and disposing of the oil can be solved by any conventional method used for transporting petroleum liquids. This includes the use of drums, pipelines, tanker barges, portable tanks, or floating tanks. Such items are generally available in good quantity in the areas where petroleum is being handled.

From discussion in the previous chapters it will be seen that with the present state of the skimming technology wide spread use of separating skimmers is not forecast at an early date. Such use as is realized will probably be on small operational spills in relatively calm waters and will yield small volumes of oil to be transported.

In spills which involve substantial quantities of oil, (50 barrels and more) the probability is high that non-separating skimmers will be used for some time to come, and the oil/water mix emerging from those skimmers will have a much lower oil/water ratio, probably in the range of 20% oil to 80% water.

When a large spill is handled by non-separating skimmers, the total volume of the oil/water mix may be large enough to pose a handling problem. Therefore it is important to perform some separation of the oil from the water at the earliest possible point in the system.

There was no separating skimmer available to this project. Skimmers tested delivered oil/water mixes as low as 5% oil. Two variations of a system for separating, reclaiming and disposing of the recovered oil were used. Each of these systems included the use of gravity separation. With smaller amounts, (spills of 50 gallons and less) it was possible to use a gravity separator tank on shipboard. When larger amounts were involved a floating tank was used as a gravity separator during transportation of the oil/water mix from ship to shore and a secondary gravity separator was mounted on the docks alongside the testing area. In either case, the intent was to achieve some separation as early as possible in the process so that the separated water could be drained overboard and the total volume of liquid handled beyond that point could be minimized. (Exhibit 17.)

Details of each of the above systems follow.

Shipboard Separation Systems Used in the Project

In the early stages of the project when oil test spills were very small (less than 20 gallons per spill) it was possible to use a very small but effective separating system mounted on the work barge.

A 280 gallon household fuel oil tank was skid-mounted and placed in the working area of the barge.

Oil/water mix pumped from the skimmer was delivered directly into the tank which was mounted in a vertical position as shown in Exhibit 18 .

Because the quantities of oil spilled were very small (20 gallons or less) the oil/water ratio was expected to be about 10% oil/90% water by the time the oil/water mix reached the tank. Under those circumstances the capacity of the tank would be barely sufficient to contain enough oil/water mix to clean up all of the spill and in some cases a two batch process was planned.

On the first tests, however, gravity separation inside the 280 gallon tank was taking place far more rapidly than had been expected. This was true even though the oil/water mix had been pumped into the tank through an impeller type centrifugal pump which emulsified the oil.

Nevertheless the oil did separate rapidly so that it was possible to drain clear water from the bottom of the tank after the tank was about half full.

This accelerated procedure was sufficiently effective to accumulate the separated oil from 3 or 4 spills before it was necessary to empty the contents of the tank into a storage container on shore.

This type of system would be satisfactory for many of the small operational spills which are encountered in a harbor and a ship-mounted tank of even 500 gallons capacity could provide adequate capacity to hold the oil from many of the small spills encountered.

Floating Tanks as a Separating System

When the project had gone forward to the point of making larger oil spills (100 gallons per spill) it was evident that the 280 gallon capacity of the barge mounted tank was insufficient for a continuous operation.

The possibilities of using a floating fabric tank for the storing, transporting and perhaps separating of substantial quantities of oil/water mix had been noted.

The Needham office of the FWQA found a fabric tank of 5,000 gallon capacity and arranged to make it available for use on the project.

This particular tank was not designed for marine use. Necessary modifications included auxiliary flotation, inlet hoses, discharge hoses and an air vent so it could be used with skimmer pumps and transfer pump equipment.

Equipped with this tank (See Exhibit 19-20), as much as 5,000 gallons of oil/water mix could be pumped directly from the skimmers into the floating tank.

Here again gravity separation of the oil and water made it possible to start draining clean water from the bottom of the tank 30 or 40 minutes after the pumping started.

In those instances wherein 3 or 4 thousand gallons of mix were pumped into the tank and then towed to shore, primary separation was well underway when the tank arrived at dock-side. When the clean water had been drained the residue in the tank was 80% oil or better.

At this point the contents of the tank were discharged into vertical separator tanks mounted on the dock alongside the testing basin. (See Exhibit 18.)

Each tank held 1,000 gallons. A settling period of one hour was sufficient time in these vertical tanks to achieve sufficient separation so the clean water could be drained off. The residue in the tank was useful oil. This oil was re-used for oil spill purposes but it could well have been returned to a refinery for complete reclamation.

From the description above it will be seen that there is a vast inventory of equipment which can be readily pressed into service for use as components of an oil handling, separating, transporting and storage system. Some of the items which are available in most areas for this type of work include:

a. Drums or other open containers. (55 gallon capacity)

b. Skid-mounted tanks of almost any size (200 gallons and up) or shape which have adequate openings at the top to receive the oil and workable drains near the bottom for discharge.

c. Metal and fabric pipes and hoses of all sizes and styles with their appropriate valves and fittings.

d. Pumping equipment as required.

Incineration of Sludge Wastes

In any refinery operation there develops a sludge which cannot be used industrially. Various methods are used for disposing of this. Some refineries have burning pits where the sludge is periodically disposed of by incineration.

Considerable improvement can be made in the incineration process and this is discussed in the following paragraphs.

Now that air pollution is a matter of prime importance, some careful attention should be given to the use of equipment whereby pollution of the air is avoided when incineration must take place.

There are two or three equipment suppliers who manufacture highly efficient oil burners which might accomplish this type of incineration without generating air pollution.

There are reports that such burners have been installed in paper mill dryers where the products of combustion went directly into the drying of white paper and were so effective that there was no visible evidence of any particulate matter adhering to the paper produced under those circumstances. The type of burner described above has been on the market for over 15 years, its operation is well understood and the burners are highly reliable under a wide variety of industrial applications.

This is the logical avenue to explore for the incineration of large quantities of sludge oil or, in some cases, for the disposal of quantities of recovered oil when those quantities are too small to justify transportation to a distant refinery.

It is conceivable that the high-efficiency burners described above could be mounted effectively on ship-board and operated at the site of an oil spill if it became desirable to do so rather than to attempt transportation of the recovered oil.

Addresses of the manufacturers of this equipment and additional technical information are available upon request.

Alternate Waste Disposal Methods

The problems of disposing of sludge oil by other than incineration are apparent and should be well known by anyone active in the petroleum industry.

Burying oil or pouring it on a dump or burning it by conventional methods are less than satisfactory answers.

In some areas there are companies which collect sludge oil, used crankcase oil and other contaminated oil products. This waste oil can be used satisfactorily on industrial roads or areas where some sort of surface treatment is required to support wheeled traffic.

If underground disposal must be made, careful selection of the site minimizes the problem of leaching of oil into water systems or other areas which should not be contaminated. The site must be chosen with great care and with full attention to any regulations governing underground disposal which might apply in the area.

Conclusions and Recommendations

Conclusions:

1. In any system of oil recovery and disposal, primary separation of the oil from the water should be introduced as early in the system as possible so that the problem of handling large

volumes of oil/water mix is minimized.

2. Under most conditions, and with most types of oil, the gravity separation system is so simple and dependable that it should be given first consideration.

3. When and if shipboard separators (such as centrifuges or other techniques become available), such equipment should be introduced into the system at the earliest possible point to reduce the volume of liquid to be handled.

Recommendations

1. The ultimate objective of the recovery and disposal system should be to deliver the largest possible quantity of reclaimable oil to an oil refinery which can receive it.

2. The use of high pressure and high efficiency oil burners should be explored as a method of ultimate disposal of non-reclaimable oil sludges.

3. At the present state of the art, the design and operation of equipment to receive oil from the skimmer pumps and to handle it through ultimate disposal will depend on the type of equipment which is available at or near the location of the spill. In most areas where oil is being handled or transported in any volume, there is probably an adequate inventory of pumps, piping equipment, valves, tanks, and other accessories which can be mounted on surface craft or assembled at strategic shoreside locations so that systems such as described above or variations of them can be put together and operated effectively.

4. It is suggested that attention be given by government and industry to providing large fixed and specifically designed shore-side separator units. Vessels carrying petroleum products could then tie up at place of loading and discharge the remaining ballast into separator tanks rather than discharging ballast into the sea. These units would be strategically placed at loading points.

   (Note: This type of installation was called for in a Presidential message delivered on May 20, 1970.)

THE "SYSTEMS" APPROACH

Outline of a Complete Clean-up System

This Section of the report is written to emphasize the need for a "Systems" Approach in dealing with oil spills.

Obviously, prevention of oil spills is the ultimate answer to the problem, but until prevention is 100% effective, there must be a clean-up capability to minimize the damage.

A complete clean-up system begins with the make-ready activities of organization, equipment procurement, training and their sub-divisions. The actual removal of oil from the spill begins with the detection of the spill and follows a sequence of events leading to final disposal of the spilled oil and make-up of the equipment in preparation for re-use.

Testing and evaluation of equipment on this project, has emphasized the requirement that each unit must be compatible with other units to form a complete system.

For example, it should be possible to fasten a mechanical barrier to a skimmer so that no oil can leak out at the joint. A skimmer pump must be able to deliver its discharge high enough and far enough to reach a tank on the deck of a barge or on a dock. The tank, in turn, must be an effective unit in a separating or disposal system.

A thorough understanding of the inter-dependence of units will benefit personnel responsible for all phases of preparations, training, planning the attack on a spill and operation of the equipment as well as those who design and manufacture equipment for oil spill control.

The inter-relationships effecting each phase of the operation are complex. Consequently, the balance of this Section reviews all stages of the process and points out some of the instances where the success of one unit depends on the proper operation of the unit which precedes or follows in the sequence.

The make-ready activities of organization, equipment selection, procurement, and the training of personnel are outlined in Appendix D entitled "Community Response to the Oil Clean-up Challenge".

In addition, Appendix A contains detailed reports on several special projects wherein the inter-dependence of various phases of the operation and the value of the

Systems Approach should be readily apparent.

It is obvious that whenever the prevention part of the program fails, the clean-up system operates until eventual disposition has been completed and the equipment is ready for re-use.

The various stages of the clean-up program include:

1. Detection
2. Location
3. Analysis
4. Containment
5. Compaction
6. Removal
7. Storage, Separation and Sludge Disposal
8. "Make-up" of Equipment

Equipment and facilities needed for each stage of the operation are described in other Sections of this report. Good equipment is already available for some portions of the operation, new developments are known to be underway, and new approaches to some of the problems will appear at an increasing rate as new research is focused on this situation.

Detection

This section should really be entitled "Spill Alarm". This term is suggested to emphasize the need for rapid action just as in the case of reporting a fire. It is unfortunate at the present time that oil spills are not so considered. Many oil spills go unreported for days or weeks although they may have been observed by many personnel who could have reported their presence had the urgency been understood.

Many oil handling activities are prompt and conscientious in reporting oil spills.

Nevertheless, in the open waters or along sections of the coast which are sparsely inhabited spills may remain unreported because no immediate economic danger is recognized and the observer may hope the problem, if ignored, will disappear.

Crews on commercial vessels of all categories should be alert by now to the potential danger of an oil spill. Many other groups, however, have not been told where to report spills so that active counteraction can be started.

Coast Guard Bases are an obvious communication center. In addition, the harbor master or the local fire department, yacht clubs, power squadrons, city officials, bridge tenders and many others constitute an increasing network of knowledgeable persons who know how to "ring the alarm" in a particular area.

The reporting of oil spills from the air can be very effective but very little has been done to alert pilots of private, commercial and military aircraft to the need of reporting oil slicks. All commercial and most private aircraft are in almost constant communication with FAA radio stations. This provides a very effective channel for initiating the oil spill alarm. (See Appendix A.)

At the time of this report, there is no satisfactory method for detecting oil spills promptly during the hours of darkness. Research has been initiated and proposals for development range from continuous inspection by visual means to improved photography from satellites in space.

Inasmuch as time is extremely important in the early stages of an oil spill it would seem that attention to this problem of reporting should receive high priority for intensive research.

Location

Just as in reporting a fire, accurate location of the spill is of extreme importance in the first report.

Given the infinite combinations of water conditions, terrain, wind, weather, tide, size of the spill and the type of material spilled, the need for accurate location is evident.

Even this is only a part of the problem because oil spills travel across the surface of the water under the influence of tidal currents and surface winds to such an extent that their change of position is of continuing concern and the prediction of the course is difficult.

When one understands the time required to marshal the clean-up force and equipment, the importance of tracking a reported spill becomes self-evident.

A recent spill near an oil terminal in Portland Harbor, Maine occurred just after midnight when visual observation of the extent of the spill and its track was almost impossible.

In this instance, the placing of an oil boom was prompt and, under the circumstances, extremely effective. Nevertheless, some portions of the spill had drifted outside the area surrounded by the boom and it required prompt action by a local helicopter to find these other patches of oil early the following morning before they impacted on sensitive areas in the nearby harbor.

If an oil spill followed the known tidal currents in the area an application of dead reckoning calculations would be most helpful in predicting the track of an oil spill. However, local surface winds can push an oil spill against tidal currents and at surprising speeds. This makes it important to know the local weather conditions in more detail.

Improved forecasting of the track of a spill, plus good communications, would make the job of getting to the spill much easier and would save precious time.

Analysis

The volume which has been spilled and the type of oil is also very important to the planning of effective counter measures.

A spill of highly volatile oils may yield to the evaporation process and disappear completely into the atmosphere under some circumstances. Off-shore, such a spill might simply be ignored while nature takes it course, while the same spill in a harbor area might be a serious fire hazard calling for immediate clean-up effort.

In any event every detail of the spill is important to the individual who is responsible for marshalling the clean-up activities and directing the personnel involved or for alerting shore installations which might be threatened by an approaching oil slick.

Characteristics of an oil spill vary over wide ranges and cannot be determined accurately without close inspection.

The type of oil, the thickness of the oil film, temperature of the water and other items can best be determined by surface inspection methods at present.

It might be worthwhile to develop a technique for extracting a sample from the central area of an oil slick by some application of a pick-up device operated from a fixed wing or rotor wing aircraft. At many locations such technology could provide critical information much faster than by surface methods.

Containment

Containment of an oil spill by means of a surrounding barrier is a key operation in preventing the continued spread of the spill over a wide area and perhaps in limiting or controlling the movement of the spill under the urging of wind and current conditions.

The same equipment which is used to contain the spill may also prove to be useful in compacting the spill as part of the preparation for the removal process.

Unfortunately, many of the mechanical booms have not been designed to work effectively as a component in a system primarily because other components of the systems are themselves still in a formative stage.

As a result mechanical boom "A" may be awkward and difficult to handle in connection with oil skimmer "B".

Compaction

Compacting of an oil spill is the process of gathering the edges of the spill toward the center so that the thickness of the oil film is increased.

Compaction will sometimes be accomplished by maneuvering a boom or other type of barrier so that the enclosed area is gradually reduced. Under most circumstances it may be accomplished by action of the underflowing current or by surface winds.

The advantages of compaction are evident because most oil removal equipment functions more rapidly and more efficiently in a film 1/2" thick or more but the efficiency deteriorates rapidly as the film becomes thinner.

Consequently, designers of barrier equipment should give more attention to the ability to compact a spill. The boom or barrier should control the spilled oil in a manner to provide good working conditions for the skimmer and the boom should never become an obstacle to the successful operation of the skimmer.

Removal

Skimming equipment has been discussed in some detail in a previous Section. Many new skimmer designs are well along in the development stage or are being offered to the trade as finished equipment.

While some of the skimmer designs include components for containment, removal, and storage functions, most skimmers are limited to the removal function and must team up with other equipment to be useful.

In either case, the Systems Approach suggests that skimmers should be compatible with the equipment which precedes them or follows them in the clean-up process. Designers and manufacturers should work constantly to make their equipment and supplies function as an effective part of the complete system.

Storage, Separation and Sludge Disposal

In the removal process some type of storage must be provided.

In all but the smallest slicks, it is probable that more storage capacity will be required than can be provided in the vessel which carries the removal equipment.

Storage capacity may be combined with separation facilities whether on board ship or ashore. For example, any tank which is equipped with a drain valve near the bottom can be used for gravity separation of oil from water. Such a tank might be the hold of a tanker vessel or the hold of a barge or a tank available in a nearby shore installation.

Sludge is generated at the separating tanks, and some provision must be made for its disposal. Incineration equipment is recommended as described in the Section on Reclamation and Disposal.

"Make-up" of Equipment

The final stage in any clean-up is to prepare the equipment for the next use.

This can be an arduous task requiring costly hand labor unless the equipment supplier has designed for easy cleaning and storage. Attention should be given to powered cleaners or other accessories which facilitate the cleaning process.

Cleaning should be accomplished in an area which can contain the oil and other pollutants removed from the equipment. Waste from the cleaning operation must not be allowed to drain back into the ocean, thus becoming a secondary source of pollution.

In either event, the Systems Approach dictates that this final problem be given proper attention.

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Appendix A

SPECIAL PROJECTS

There are many occasions in a clean-up operation wherein an improvement in one part of the operation could contribute to the success of another part. The following paragraphs describe several such occasions encountered in this project where the "Systems Approach" can produce a synergistic reaction.

Aerial Reporting of Oil Spills

Since 1967 there have been several instances of oil spills in remote areas of the Maine Coast which have gone undetected-or at least unreported-for several days. Several such spills have been found eventually and reported to the Coast Guard, but the chances of determining the cause and responsibility after such delay are quite remote.

Over the same period of time, there have been several spills reported to personnel of this project wherein the pilot or passenger in an aircraft has been able to observe and report a spill.

Repeated instances of effective reporting have confirmed the feasibility of aerial observation of oil slicks. The Annual Report on this project, dated October of 1969, noted this circumstance. It also noted that there was then no established procedure for reporting such observations to a communications network which would pass the word to the Coast Guard or to other authorities having the know-how to start the ball rolling on clean-up operations.

The circumstances described above were related to F.A.A. Air Traffic Control personnel at the Portland, Maine International Jetport and to the Commanding Officer of the U. S. Coast Guard Base in South Portland, Maine, in September, 1969.

FAA personnel confirmed that pilots of itinerant aircraft (Military, Airline or General Aviation) were in frequent communication with Flight Service Stations or Air Traffic Control Centers and that reports of oil spill situations could be transmitted to those facilities and then relayed to the Coast Guard.

Development of this procedure into a viable system would not require new equipment or technology, although some publicity and guidelines for such reporting would be helpful.

A suggested plan for the system is included as Exhibit 21.

Coast Guard personnel in South Portland, Maine, indicated a willingness to receive such reports, screen them and take appropriate action. The Commanding Officer emphasized that the ability to receive early notification of bonafide spills was so important that it would outweigh the inconvenience of an occasional false alarm or duplicate reports on spills already reported.

As this report is written, a press release dated October 13, 1970, (Boston, AP) quotes the Commander of the First Coast Guard District in Boston as asking that airline and other pilots, police and persons who travel along the coastlines be alert to spot oil spills and to report them.

Widespread adoption of an aerial reporting system along the lines described above would improve the operation of detecting an oil spill with minimum delay and this, in turn, would accelerate the subsequent clean-up operations.

First Echelon Chemical Analysis

In many oil spill situations, it is desirable to analyze samples of the oil to determine its chemical content, its viscosity and the thickness of the slick.

In situations where the source of the spill is unknown, analysis of the spilled oil may lead to eventual identification of the source so that responsibility for the spill can be determined accurately.

The core-sampling technique which was developed as part of the testing technology of this project is described in an earlier Section of this report and is illustrated in Exhibit 1. While the equipment used was crude and was operated from a surface vessel, the procedure was satisfactory for obtaining a rough measure of the thickness of the slick. Further development of the technology might permit samples to be taken from aircraft. Such samples would not only measure the thickness of the slick, but would provide a sufficient quantity for chemical analysis. This would be useful in dealing with a mystery spill, particularly if it were found at some distance from the nearest shorebased clean-up facility.

Facts derived from analysis of samples would assist in the effective planning of clean-up operations and the dispatching of most suitable equipment to a distant spill.

Oil Slick Warning Systems

Experience in Portland Harbor has indicated a definite need for a means of advising the boating community whenever oil pollution is present in local waters.

Various types of warning systems are being considered, including sound signals, light signals or a distinctive pattern of floating buoy which could be anchored in or near a polluted area. (See Exhibit 22 .)

Air Born Command Post for Coordination of Anti-Pollution Efforts

In all activities of a clean-up effort it is evident that the tracking of the slick and the proper position of boats, booms and other equipment can best be coordinated from an elevated observation point.

In rough water tests in Portland Harbor we observed from a position on the pilot house of the Portland Fireboat, or from the flying bridge of a Sport Fisherman. Such location, 20' or 30' above sea level provides a great advantage over a position on a work boat at sea level. Exhibit 23 .

These conclusions have been made known to the Maine Port Authority. That organization has just completed a heliport on the roof of the Maine State Pier. This provides a base from which to operate the helicopter which is occasionally used as an air born observation point when an oil spill is being attacked at some distance.

Systems Test Combined with Photometric Test - October 9, 1969

OBJECTIVES - This test had two objectives as follows:

1. To demonstrate that proper booming technique could contain the oil spill on the surface of the water and move the spill to another location where clean-up operations could be completed.

2. To determine the efficiency of photo measurements of the spillage, containment and clean-up of a 100 gallon spill.

PROCEDURE - Photo measurements of the results were taken from an airplane flying at an altitude of 800' over the site of the spill. The plane was equipped with specialized photo equipment supplied by Singco Corporation and operated by Singco personnel.

Physical measurement of the spill was taken by project personnel. Time logs, colored photos, observations and chemical measurement of core samples collected during the test were included.

PREPARATION - A coordinated schedule for air and ground operations was prepared and reviewed with all personnel.

AMBIENTS - The test was conducted outside of the testing basin at South Portland, Maine. Wind northwest at 6 knots, sea calm, tide falling, current at the spill site was south to north.

The time log of the experiments contained the following entries:

11:50 a.m. Singco plane arrived at Portland Airport. Equipment deployment had been completed at the test site.

12:55 p.m. Plane arrived overhead at the test site.

1:02 p.m. Started spill procedure.

1:34 p.m. Two 55 gallon drums of oil had been emptied into a floating pen formed by a light fence type boom rigged into a pen approximately 40' on a side and towed behind the work barge.

1:37 p.m. The oil slick had covered the area inside the pen completely.

1:50 p.m. The pen was moved very slowly to a position about 200' off the pier head. During this movement of the pen with the oil contained inside, any relaxing of the tension on the tow points of the boom allowed the boom to sag so that a few pints of oil escaped over the top of the boom. Improvement in towing technique could have avoided this loss. (Exhibit 6 .)

2:05 p.m. The oil spill was uniform throughout the extent of the boom and the first core sample was extracted for laboratory measurements.

2:10 p.m. Skimming procedure was started. The skimming pump was operated at idle speed so that a thin skim could be extracted.

2:15 p.m. A core sample was extracted for laboratory measurement. At this point it was established that the wind was pushing the slick toward the south end of the enclosure. This effect plus the rapid removal of oil by the skimmer caused large clear spots to appear over about 1/3 of the enclosure area. The pump was still running at idle speed but it was beginning to pump some water along with the oil.

2:25 p.m. Core sample No. 3 was extracted.

2:40 p.m. Core sample No. 4 was extracted. At this point 2/3 of the enclosure was clear of oil.

2:45 p.m. At this point the contour of the pen was changed so that the light breeze could clean out oil spots in corners of the pen protected from the wind by the freeboard of the boom. This maneuver was effective and the remaining oil moved immediately to the downwind side of the pen where the skimmer was operating.

2:55 p.m. At this point the skimmer was operating in a very thin film of oil and was producing a low oil/water ratio. Only two or three square feet of spill remained to be cleaned.

3:07 p.m. Clean-up completed.

3:10 p.m. Core samples No. 5 and No. 6 were extracted for laboratory analysis to determine effectiveness of the clean-up.

3:35 p.m. Output of the skimmer had been pumped into a floating tank. The tank was now towed to dockside. In the process, it served as a primary separating tank as well as to transfer the oil residue to separating tanks on the shore.

3:50 p.m. The boom was collapsed and towed to dockside and stowed.

Commentary on the Tests

The first objective of the test was realized. The 100 gallon spill was held satisfactorily inside a containment boom (a light fence type), towed a distance of more than 200' without unavoidable loss and cleaned up satisfactorily at the new location. Similar technique would be useful in moving a spill of fuel oil or other combustible substance away from a dangerous location before starting clean-up operations.

The second objective was partially completed. Pictures of the entire operation were taken at intervals of about 5 minutes from an elevation of 800 feet. Photo equipment was mounted in a Cessna 172 aircraft which flew a rectangular pattern over the test site. Infra-red film, Tri X Pan film and Kodachrome II were tested. The Kodachrome II was lost enroute to the developer, but prints of the Infra-red and Tri X Pan film were clear. (See Exhibit 27 .)

The black and white prints showed excellent definition of the oil coated areas of the water at all stages of the operation. When a small amount of oil escaped from the boom (perhaps 1 quart volume) the very thin, iridescent slick outside the boom was hardly noticeable from the surface, but the Tri X Pan film showed that slick escaping from the boom, spreading out into a streamer about 20 feet long by 3 feet wide and gradually changing position under the influence of wind and tidal current.

A more detailed report on the film technique was made by Singco Corporation. The complete text of the report is included as received. (Appendix F .)

Disposal of Oil/Water Mix

The oil/water mix removed from the boom on October 9th remained in the 5,000 gallon floating tank for 5 days. On October 14th transfer of oil to the separating system on the dock was started.

Initial draining from the tank was completed in about 15 minutes of full throttle pumping. During this time clear water was being pumped steadily. When the first trace of oil appeared the output was pumped into the 2,000 gallon separating tanks on shore. The volume remaining in the fabric tank at the time of the switchover was estimated at 150 gallons of oil/water mix. It required only two minutes pumping time to transfer it to the shore tanks.

Within six hours the final separation of the oil from the water had taken place in the vertical separating tanks on the dock.

Funnel Boom Test

In February of 1970 a special test was arranged to determine the ability of two booms, towed independently, to produce a "funnel" effect and to channel oil into a skimmer towed at the small end of the funnel.

Equipment included two tow boats, two light fence booms, each 160 feet long, the articulated skimmer prototype (as developed on this project (See Exhibit 23 .) pumping equipment and a 5,000 gallon floating fabric tank. The Portland Fire Boat served as a headquarters and observation post. (See Exhibit 23 .)

Tow tests were conducted in Portland Harbor on calm seas with occasional waves from passing vessels. There were many small pieces of ice floating on the surface. Towing speed was 1½ to 2K.

Results of the test were as follows:

a. With the tow boats 200' apart as in Exhibit 24, the funnel collected far more surface water in the Vee than could run out through the skimmer. Consequently, turbulence developed along the curve at the sides of the funnel. If oil had been present, there would have been substantial loss under the boom. Even some of the ice cakes were carried under the boom by the induced currents.

b. By positioning the tow boats at an interval of 100' the surface water collected in the Vee was reduced so that very little loss of oil would have occurred. See Exhibit 24.

c. It was evident that the same area could be swept using shorter lengths of boom, and this would also reduce the tendency of the booms to curve and develop turbulence.

d. Many of the ice cakes caught inside the booms were diverted into the entrance of the skimmer and actually pumped into the sump of the skimmer.

e. Rough water tests were planned using the same equipment layout and with shorter booms, but before the rough weather arrived, Project personnel were diverted to the Louisiana spill as reported in the Appendix on that incident.

Diversion Boom Test

The final oil spill test in the project was conducted on April 16, 1970. The objectives were:

a. To demonstrate a Diversion Boom technique in open water, using a single boom placed at an angle across the normal path of an oil slick, and thereby to divert the oil to a skimmer, and

b. To demonstrate pumping action of the skimmer.

Equipment was positioned as shown on Exhibit 8. Wind from the Northeast was steady at 6 Knots, and was controlling the movement of surface objects. Current was negligible.

Oil was spilled at the up-wind end of the boom as shown on the Exhibit. The boom was anchored at that end and fastened to the skimmer at the down-wind end.

In 4 minutes the spilled oil travelled the 50' length of boom and floated into the sluiceway leading to the skimmer. At that point the skimmer pump was operated and all the oil in the spill moved into the skimmer sump ready for pumping into a floating tank, separation and disposal.

The boom had been deployed carefully so that it did not cross the normal path of the oil flow at more than 20 degrees. (The greater the angle of boom to oil path, the more tendency for turbulence to develop and to lose oil under the boom. 20^{o} seems to be about the maximum angle permissible under conditions described.) The boom was fastened to the skimmer with the telescoping fastening device which has been used successfully throughout our project.

As a result, all the oil was contained, diverted to the skimmer, removed from the water and delivered to the skimmer, removed from the water and delivered to the skimmer sump without leakage at any point in the process.

The Diversion Boom principle performed as desired under these test conditions, because <u>all elements</u> of the system performed their tasks effectively and contributed to the necessary end result - that of removing the spilled oil from the ocean and delivering it to the oil disposal system.

It seems evident that this Diversion Boom technique can be developed to the point that it will be effective even in rough water conditions.

Modifications of Commercial Equipment

Testing of commercial equipment loaned to this project by suppliers gave evidence of many opportunities to improve various features of the equipment.

Careful records were kept whenever opportunities for such improvement became apparent, and detailed reports were sent to nine of the suppliers listing favorable and unfavorable items and making suggestions for modification whenever possible.

At least four of the suppliers have advised that they modified their equipment to overcome the problems which became apparent from the testing program of this project.

Copies of correspondence with the suppliers have been assembled into a single volume which has been sent to the project Contract Officer for in-house circulation.

Appendix B

THE LOUISIANA SPILL----February/March 1970

Introductions: Disaster and Opportunity

On February 11, 1970, fire broke out in the engine room of "C" Structure, an offshore oil well platform belonging to the Chevron Oil Company and located about 70 miles southeast of New Orleans and 14 miles east of the town of Venice, Louisiana, on the Delta of the Mississippi River.

The fire was one of the worst in oil well history. It consumed all burnables on the structure and destroyed all production equipment on the platform. 22 oil well casings emerged from the ocean bottom at that point and had been controlled at "C" platform. At the time of the fire about half of the 22 wells were producing oil, gas or a mixture of the two. The other wells in the structure were not productive.

The oil and gas emerging from the damaged casings fed the fire and the resulting flames formed a roaring torch as high as 200' above the surrounding waters.

Oil well fires are not unknown and the technique for extinguishing them has been successful for many years. The Chevron Division which operated the oil well lost no time in calling the Red Adair Company of Houston, Texas, to plan for extinguishing the fire, and operations for that purpose got under way.

The worse aspect of the fire was the potential for a disastrous oil spill. "C" Structure had been producing nearly 2000 barrels of oil per day prior to the fire. As long as the fire burned fiercely it was expected that most of the oil emerging from the damaged well casings would be consumed by the flames and oil pollution in the surrounding waters would be minimal, and this proved to be the case.

As soon as the fires were extinguished, however, any oil gushing from the damaged wells would fall into the ocean and a massive oil spill situation would develop. This also proved to be true.

The Company sought help from many sources both within and outside of the petroleum industry. Surprisingly enough, the Company had heard of the testing project in Portland Harbor and on February 12th a telephone call to Portland asked for project personnel to go to New Orleans to give advice and assistance on plans for minimizing the oil pollution and for cleaning up the spill which was expected.

At that time, the project was in its final month of testing. A leave of absence from the project was immediately obtained from the FWQA and the senior consultant on the project flew to New Orleans for a conference on February 14th. He stayed on the job for 5 weeks.

It is not often that a research project has an opportunity to test its findings so quickly and on such a large scale. Lessons learned on the testing project were made available to Chevron and to all the other personnel who were assembled to work on the problem. Techniques developed on the project were useful in deploying oil spill booms, controlling the flow of oil after the fire was extinguished, guiding the flowing oil to areas where skimmers could remove the oil from the water, separating the oil from the water and delivering the recovered oil to a refinery where it became useful product. Something over 30,000 barrels of oil was skimmed from the ocean surrounding the "C" Structure, perhaps as much as 36,000 barrels.

This was the largest recovery of oil from the oceans surface in all the recorded history of oil spills. The volume recovered was probably 85% of the total spilled, and the recovery of such a volume took the muscle out of the spill and was a major factor in preventing the oil from reaching the mainland.

The following paragraphs of this Appendix report the highlights of the planning, equipment procurement, training and operation of the clean-up program as observed by the consultant from the testing project who worked on the Louisiana Spill for the Chevron Division.

Analysis of the Situation----February 14, 1970.

As of February 12, Chevron had very little oil spill equipment on hand in Louisiana. 1000' of curtain boom had been obtained locally and 1400' of 36" light fence type boom had been ordered. The consultant suggested placing orders immediately for additional light fence type boom and advised Chevron where it could be obtained.

Supporting equipment was available in considerable volume at the oil field base in Venice, Louisiana and in the New Orleans area. Work boats, crew boats, amphibious planes, helicopters, and a very efficient microwave telephone network plus land lines (to "H" Structure 2 miles from the fire) provided transportation and communications.

As of February 14, additional equipment began to pour in to the Venice base. Marine equipment included anchors, lines, marine hardware, buoys, floats and all the support equipment used in oil field work.

Steel plates, tubes, pipes, casings, auxiliary pumps, and engines arrived by the truckload. Portable welding and cutting equipment was ordered to supplement the inventory usually maintained at the Venice base. The staging area at Venice rapidly came to resemble a military base for an amphibious assault force.

At the first full scale conference at Chevron Divisional headquarters on February 14, basic assignments were made. Responsibilities were delegated to several task forces to work on fire fighting in cooperation with the Adair Company, a "Pollution Team" was assembled to develop a plan for combating the oil spill, specific duties and responsibilities for procurement, land transport, water transport, air transport, housing and communications were determined.

At that time, it was announced that the pre-fire production rate on "C" Structure had been 1800 barrels of oil per day. That volume had been flowing from a group of 12 well casings on the platform, and the other 10 wells had become unproductive and were considered plugged.

The Pollution Team was made responsible for estimating the volume of oil flow which could be expected after the fire could be put out, and to plan the equipment program, crew selection and training and the operating plan for cleaning up the expected oil spill. The consultant from the Portland Harbor Testing Project was assigned to the Pollution Team, working with 5 Chevron engineers and assisted by field representatives of equipment supply houses, research and engineering personnel from Standard Oil of Southern California (parent company of Chevron) and of the Shell Oil Research Laboratory at Houstin, Texas.

Weather situations could be very important, and a local meteorological service was employed to brief the group on prevailing weather patterns and to supply up-dated forecasts around the clock every four hours. This service was continued throughout the program and proved to be of great value in planning day to day operations.

Briefing indicated that on a year-round basis prevailing winds would be from the Southeast. This was the worst possible direction as such winds would tend to drive spilled oil from the "C" Structure directly toward the oyster beds and wild-life refuges which were abundant on the Eastern side of the Delta and Southeast of New Orleans. However, at that season of the year the prevailing pattern could be expected to include cyclonic storms travelling across the Gulf of Mexico, and resulting wind patterns would probably go around the compass every two or three days. This prediction was generally accurate. Four storms of severe intensity were experienced during the next five weeks.

On Sunday, February 15, the Pollution Team made an aerial reconaissance of the oil field and the burning structure. As predicted, most of the gushing oil was being consumed by the fire and no large slick was apparent in the area. Later it was learned that partially consumed blobs of oil were falling into the ocean in some quantity, but most of the light ends of oil had been burned out of them, and they did not spread into a continuous film of oil.

The Pollution Team was quartered initially at the Venice base and addressed itself to the planning of clean-up operations which would have to start on a full scale as soon as the fire could be extinguished. That date was expected to be about March 5.

The Equipment Build-up - Skimmers

Upon arrival at Venice it was found that Chevron had provided two 130' work boats, each equipped with two 40' spray outriggers, inductors and a deckload of detergents for disposal operations. Plans for the spraying operation were abandonned, however, in view of the decision by FWQA that such spraying would be extremely harmful to the ecology.

Mechanical removal of the oil spill became mandatory, and it was immediately evident that there was no supply of skimming equipment anywhere in the country to meet the requirements of the expected spill.

Experience with circular weir skimmers on the testing project had been encouraging and a crude copy was designed which could be built by local welding shops.

The first such skimmer was built in 24 hours by a welding crew which worked around the clock. The skimmer was fitted with a 4" discharge nozzle and was coupled to a 4" impeller pump driven by a diesel motor. Initial testing on February 17 showed that the skimmer had a through-put capacity of 440 gallons of liquid per minute. (See Exhibit 12 .)

At that time, best estimates were that a total skimming capacity of 75,000 barrels of liquid per day would be needed to handle the flow of oil after the fire. That figure was based on a maximum expected oil flow of 7500 barrels of oil per day (42 gallons per barrel) and an expected skimmer efficiency of 10% (10% oil and 90% water.)

The first skimmer, having a through-put capacity of 440 gallons per minute, would handle 600 barrels of liquid per hour or 14,400 barrels per 24 hour day. Six such skimmers would provide a through-put of over 80,000 barrels per day if each could be used at full capacity.

Sea tests were first conducted on February 21 from the work boat Van Tide. Waves were 8' high with some breaking crests driven by a 40K wind. The skimmer was buoyant and rode the waves well, the intake platform staying normal to the slope of the waves to a surprising degree. It was adjusted to skim a 3" deep cut and the input kept the 4" pump operating to capacity at all times. Inflow of surface liquid for a distance of 8' to 10' was apparent.

The Company built 20 of these skimmers (called the AK design) and later built 12 of a slightly modified design, lighter in weight and adjustable for skimming in thin oil slicks.

They were eventually deployed on skim boats (See Exhibit 13 .) and on barges. They were heavy and crude and required power lift equipment to move them on or off the boats, but they performed reasonably well.

<u>Booms</u>

By February 20, a good supply of booms had been accumulated on the site. Field representatives of the boom suppliers were active in preparing these booms for use and training personnel in assembly and launching techniques.

The problem of using the booms to best advantage was a subject of much discussion. Experience on the Testing Project indicated that booms would not be effective as a fixed barrier across the path of an oil spill, but that they could be used as trawls to collect pools of oil in which skimmers could operate effectively.

At this point, the Pollution Team commandeered one of the work boats which had been equipped with spray outriggers. A demonstration was arranged on February 22 using a light fence boom towed in a loop behind a spray outrigger. Waves were about 4' high and the boom rode the surface quite effectively. The work boat "3M2" towed such a boom for several hours in an area where the oil blobs were falling into the water from the burning well. Wherever such blobs were in abundant supply, it was possible to collect a pool of oil which almost filled the loop of the boom. Maneuverability was good, as had been expected, although the boat had to run its engines at dead slow speed to keep its speed relative to the surface at 1¼ K or less.

Skimmer Boats

The demonstration of boom handling plus the success of the skimmer tests offered the beginnings of a complete system. Chevron engineers suggested the use of skid-mounted tanks on the deck of the work boat for primary separation of oil and water mix and the result was the skimmer boat design shown on Exhibit 13 .

Within the next ten days 6 boats were equipped as shown in the exhibit and crews were trained to operate them on a 2-shift basis. Each boat carried two outriggers, two floating booms of the light fence type, two 4" pumps with diesel engine drives and one or two skid-mounted tanks of 210 barrel capacity for separating operations.

Additional equipment included portable welding equipment and oxy-acetylene burning sets. A welder was stationed on each boat and 4 mechanics were on call on nearby crew boats to handle pump and engine problems.

Later in the project these skimming boats demonstrated a capacity to collect upwards of 500 barrels of oil per boat, per day, working about 18 hours of each day. The water content of the oil was 10% or less, due to the use of the skid mounted tanks as gravity separators. Content of the tanks was emptied into tanker barges for transport to a shore based refinery.

Skimmer Barge

While the skimmer boat development was going forward, Chevron engineers mounted additional skimming equipment on a steel barge. Two Vee-shaped weldment structures served to concentrate the surface slick at two points on one side of the barge. At each point of the Vee an 8" suction nozzle and a 4" suction nozzle mounted 4" below the surface combined to give the barge a pick-up capacity in excess of 1000 barrels per day of oil. Two 1000 barrel tanks were mounted on the barge. The barge was maneuvered through the oil slick by two tugs, one at each end. Whenever it could be positioned in a portion of the slick where the oil was thick it proved to be the largest producing unit in the fleet. Mercury vapor lights mounted on the deck of the barge provided good illumination of the surrounding water so that the operation could continue effectively after dark.

The suction nozzles were not equipped with any skimming device to separate the oil from the water at the point of recovery. The design was predicated on the principle which had been adopted in Portland; namely, get the oil out of the water as fast as possible and take as much water with the oil as is necessary to do a complete job. Then separate the oil from the water later in the system. Both the skimmer boats and the skimmer barge worked on that principle and worked successfully.

The Barrier Barges

While the skimming fleet was under construction, the Company moored a string of 8 dead barges Northwest of the fire at a distance of about 1000 yards. Each barge was 300' long. Gaps of 100' between barges were closed with floating booms. The intent was to provide a barrier between the source of the expected oil spill and the most sensitive shoreline to the Northwest. This is the path wherein prevailing winds would probably generate the most dangerous threat to the mainland.

Experience in the Portland testing program had shown that such a barrier would not contain any great amount of oil for any length of time under prevailing conditions of wind and current, so skimmers and pumps were mounted along the sides of the barges toward the burning well.

The results of this effort were mixed. On four separate occasions storms drove the barges out of position, breaking the connecting booms away from the barges and destroying large sections of the booms. Different styles of booms were tried. One heavy fence type boom, manufactured almost on the site on a special barge, proved to be stable under storm conditions as long as its mooring lines remained intact. Other heavy and light fence booms foundered on the barge anchor cables and were only intermittently effective. All in all, the experience reinforced the conclusions reached at Portland that booms have only limited value when used as a barrier across the path of an oil spill.

On the plus side, the barrier barges did function well as a diversion boom on those days when the oil spill approached the barrier from a slight angle. The oil slick ran along the windward side of the booms for a distance of several hundred feet until it came to the end of the string. During brief periods, skimmers were operated effectively from the decks of barges and the oil/water mix was pumped directly into settling barges moored alongside the barrier.

Furthermore, the barrier provided a most welcome breakwater effect on several windy days and the skim boats were able to operate much more effectively and comfortably in the protected area behind the barge line.

Fire Out--Oil In

The fire was extinguished briefly on Sunday, March 8, but red-hot steel in the vicinity of the well tops re-ignited the gas and oil mixture after about 12 minutes. During that 12 minute period a substantial pool of crude oil fell into the ocean and started to move toward the Southwest, urged along by a 4K current. Sea and wind were calm.

The skimmer fleet was in position about 2 miles down stream of the "C" Structure. For safety reasons (because of a possible explosion of oil laden air if the well re-ignited) the skimmer boats were kept at this distance. By the time the oil reached the boats it had split up into a number of small rivulets. Consequently the skimmer boats had to pick up small pools wherever they could be found and the boats could not skim steadily in the thick pool of oil near the spill.

When re-ignition took place, there was no flash or explosion of any sort. The fire started as a small flame, then gradually spread until all the emerging oil and gas was burning at the same volume as before.

However, enough oil had been spilled during the 12 minute period to give the skimmer boats some good practice and to demonstrate that they would be able to work effectively.

On March 9, the second attempt to extinguish the fire was successful, and no further re-ignition occurred. On that day, the wind had changed and was blowing toward the Northwest. The skimmer boats were positioned about half a mile from the "C" Structure because the danger was felt to be minimal. They got into effective action much more quickly, and worked until dark.

The spill continued through the night, of course, and next day's dawn patrol by helicopter showed that some slicks were 5 to 7 miles away from the area. Two skim boats were dispatched to clean up those remote streamers of oil while the other boats moved in as close to the spill as possible. Unfortunately there was so much equipment moored close to the "C" Structure to support the fire fighting effort that skimmers were seldom able to get closer than 1000'.

The oil stream floating down current from the "C" Structure was 50' to 80' wide for about ¼ of a mile. Then it began to break up into multiple streams, the slick became thinner and skimming efficiency was reduced. This experience confirmed another principle developed at the Portland project; namely, skim as close to the source of the spill as possible where the oil is thick and concentrated and where the skimmers can be most effective.

Effect of Wind and Current

At this point it became apparent that the clean-up operation had to deal with two spill patterns, one responsive to tidal currents in the area and the other responsive to winds. A fine, oily mist floated on the wind for two or three miles from the "C" Structure, finally dropping into the water and becoming responsive to surface currents thereafter. This mist was coming from the one oil well which was "gushing" after the fire was put out.

Three or four other wells were emitting oil at very low velocities, and this oil dropped immediately into the ocean at the foot of the structure and was immediately swept away by the currents which reached a speed of 4K at many times.

This existence of two spill patterns, (Exhibit 25 .) often separated by a mile or more, required the dispatching of two or more skimmer boats to deal with the airborn spill. Skimming of the airborn spill was not efficient because the spill was so thin and widespread by the time it landed in the water.

Final Clean-up

As soon as the fire was out, the Adair Company personnel moved onto the remains of the "C" Structure and capped the wells which were still producing gas or oil. This process took the better part of three weeks during which time the skimming operation kept going at an increasing pace.

Equipment was tested during this period, crews increased their efficiency, mercury vapor lights were added to the skim boats so that they could work effectively at night, and the daily production of the skimming effort built up steadily. On March 13 the skimmers delivered 1714 barrels of oil (10% water or less) to the tanker barges for transport to the refinery at Pass Romere. On March 14 the score was 2367 barrels and on March 15 it was 3212 barrels.

Storms interrupted the operations on at least three occasions after the fire was stopped, but the skimmer crews developed ability to operate in rough water to a surprising degree.

The last day the Portland consultant was on the scene, skim boats were operating in breaking swells 10' high driven by a 40K wind. Captains had been given permission to run for sheltered waters at Lonesome Bayou, but elected to continue skimming. It was found that by hoisting their windward boom out of the water and skimming only with the leeward boom on the sheltered side of the boat, the operation could be continued effectively although at a reduced production rate.

By the time the last oil well had been capped several days later, the situation had been saved. No oil had reached the mainland. No oil had reached into the oyster beds. One small slick did reach an uninhabited island in the Chandeleur group. This was a game refuge and the Company had 40 men, 1000 bales of straw, a helicopter and work boats on the scene to clean that spot in a few hours.

Meanwhile, protective booms had been placed at many points along other shore lines which might have been threatened, but those resources were not used.

Obviously, there were some very favorable circumstances to assist the clean-up effort. Most important was the time interval of three weeks before the fire was extinguished. That gave opportunity to assemble equipment and personnel, train crews and plan an organized effort.

The wind was a factor both for and against the effort. If the wind had been calm, skimming would have been relatively easy. Storms tore up the barrier barges, handicapped the boat operation and rocked the boat in more ways than one. The fact that the wind changed so frequently was a big help because unfavorable winds did not persist for more than three or four days at a time.

One cannot avoid the conclusion, however, that with the continued development of equipment and with stockpiles of equipment and trained personnel at strategic locations around the shoreline, massive oil spills can be cleaned up if they do occur.

Appendix C

"OIL SPILL IN BOUNDING BAY"

(A Narrative)

This section is written for the man who has to work on the clean-up of an oil spill. He may be a workboat captain or a deck hand, an equipment dealer or maintenance man, a marine repair expert, a salvage master, a city fireman or a Coast Guardsman.

Whatever his job on the team that is gathered together to fight an oil spill, this section of the report is an attempt to pass along some practical information from other men who have faced the same problems.

Many people have worked on oil spills. They have learned a great deal about oil slicks and the kinds of equipment which can be used to clean up the mess. They have tried new equipment and seen it work in some cases and fail miserably in others.

Some of the things they have learned are described here in the hope that it will help everyone to do a better job faster and more effectively when he is faced with the dirty, tiresome and sometimes dangerous job of cleaning up an oil spill.

Fortunately, our knowledge of methods for cleaning up oil spills is growing rapidly, but we have a long way to go and there are no easy answers.

Nevertheless, there are some things we can agree upon as follows:

1. No two oil spills are exactly alike.

2. There is no one piece of equipment nor one single method of attack which will work effectively on all oil spills.

3. The attack on the oil spill must be planned in accordance with the special characteristics of that spill, the abilities of the people and the types of material and equipment which are available.

4. Time is your most important ally. Don't waste it.

5. The principle of "skimming first and separating afterwards" has been proved to be effective.

6. Recovered oil can sometimes be delivered to a refinery and reconstituted so that its value is not lost. It

need not be wasted, poured on the ground or burned to pollute the atmosphere.

7. The clean-up job is not finished until the oil has been removed so thoroughly that it can do no further harm to property or people or the environment in which we live.

We have a long way to go before we can feel secure in our ability to clean up oil spills. However, at this writing, good equipment is available at some locations to attack some portions of the problem. A lot of Research and Development work is being pushed forward by equipment suppliers. New equipment is coming on the market at an increasing rate. It can safely be predicted that workable solutions of today's problems will be found with increasing rapidity as this research effort goes forward.

The oil spill in Louisiana was cleaned up before any damage was apparent. Unfortunately, very little oil control equipment was available near New Orleans---or anywhere else in the United States, for that matter. Consequently, it took three weeks to assemble necessary equipment and to train crews.

Hundreds of men, scores of boats and airplanes, and many thousands of man hours were involved, but more than 30,000 barrels of oil were removed from the ocean. That took the muscle out of the spill, the oil that escaped the clean-up effort dispersed or was blown out to sea as a very thin "iridescent" film and eventually disappeared. The potential disaster had been averted, and oil spill clean-up technology had taken a long step forward.

The following pages of this Section provide, in narrative form, a series of "how-to-do-it" suggestions based on actual experience in two different types of oil spill.

Assume that you are in charge of oil spill clean-up for a Township on the Maine Coast. You have a contingency plan, an organization of men to work with you, a communications network and an inventory of boats and oil spill equipment. You have actually run a few training exercises, so you are better prepared than most towns to take care of an oil spill if one takes place. You hope it never happens.

7:30 a.m. The phone rings in your office on the Marine Supply Wharf. The captain of a local work boat reports an oil spill "out in the Bay". Try to get all of the following information on the first call.....and it would help if you had a reminder sheet close at hand which lists all the important questions:

Who is calling and where can you call him back if needed?

Where is the spill? (Locate it in relation to known reference points in the area, or to a marine chart)

How big does it look? (Did the caller have a chance to travel around it or did he come through it)

Is it spread widely over an area or is it a long narrow stream of oil?

What color? Does it look thick or thin?

Any apparent indication of the source of the spill? Is there a vessel involved that might be leaking oil?

What are the surface conditions in the area? Rough or smooth? Whitecaps? How much wind? From what direction? Rain or fog in the area? Does the oil spill seem to be moving in any direction? Downwind? Or across the wind? Any strong currents in the area? Are they tidal currents or rive flow currents?

From the above information you can estimate the problem and pass the information along to someone else who will take over the shoreside duties, notify the Coast Guard, answer the phone and talk to reporters. You have to go out and clean up the mess.

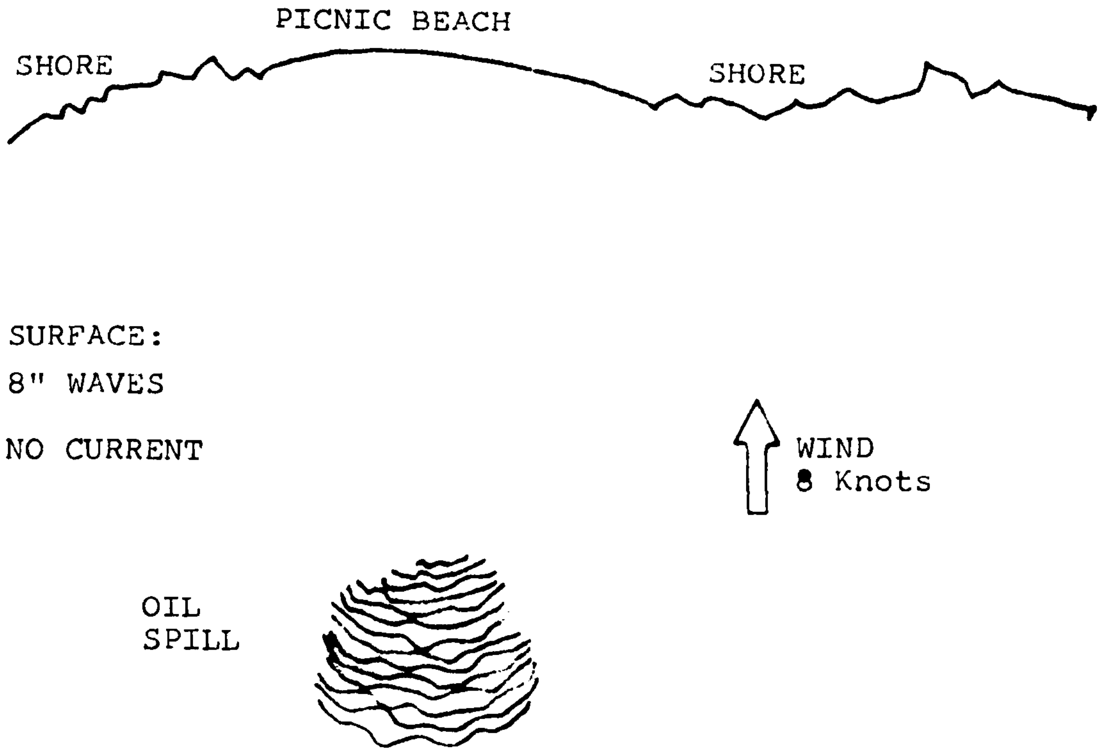
From the information received, you estimate that some passing vessel pumped its bilges and spilled about four barrels of oil sludge into the usually clean waters of Bounding Bay. The oil is reported to be black, which means that it hasn't spread too widely, and maybe covers about 2 or 3 acres of the surface. The area is generally calm without many strong currents, but the wind is blowing steadily from the South at 9 knots and will probably move the slick North toward Picnic Beach about four miles away and the tourist season is just starting.

See illustration showing the situation on the following page.

The spill will spread slowly, and the wind will cause it to change its shape from a circle to a long-tailed slick. The oil will move at a speed of about 3% of the wind velocity, or about 3/10 of a knot. In about 12 hours it will reach the Picnic Beach area. (Exhibit 26.)

At this point, your actions depend on the type of equipment available to remove the oil from the water. You

The situation looks like this:



cannot spray with detergents because there are too many lobster grounds and clam flats in the area.....and, anyway, detergents are illegal until you get permission. Your best bet is to skim the oil out of the water before it can do any harm to anyone.

You have two skimmers on your work boat. One is a small capacity model, which pumps 100 gallons per minute and is suited to shallow, calm waters. The other is a heavy duty model which can pump 400 gallons per minute. (You also have 1000' of air barrier hose, an air supply boat, and 2000' of a light, fence type boom.

Get those skimmers into action as fast as you can and at a point where they will do the most good. Use your other equipment to make the job easy for the skimmers.

You only have 4 barrels of oil (about 200 gallons) to pick up, but you may have to pick up as much as 4,000 gallons of oil/water mix in order to get all the oil out of the water. So you need your big skimmer to attack the major portion of the oil spill. Use the small skimmer to go after small patches of oil which may become separated from the rest of the slick.

What about protecting Picnic Beach? You have 12 hours before that area is threatened, unless the wind gets stronger. The wind always get stronger later in the day so you send a crew to set up the protection of Picnic Beach now while you have time to get it done.

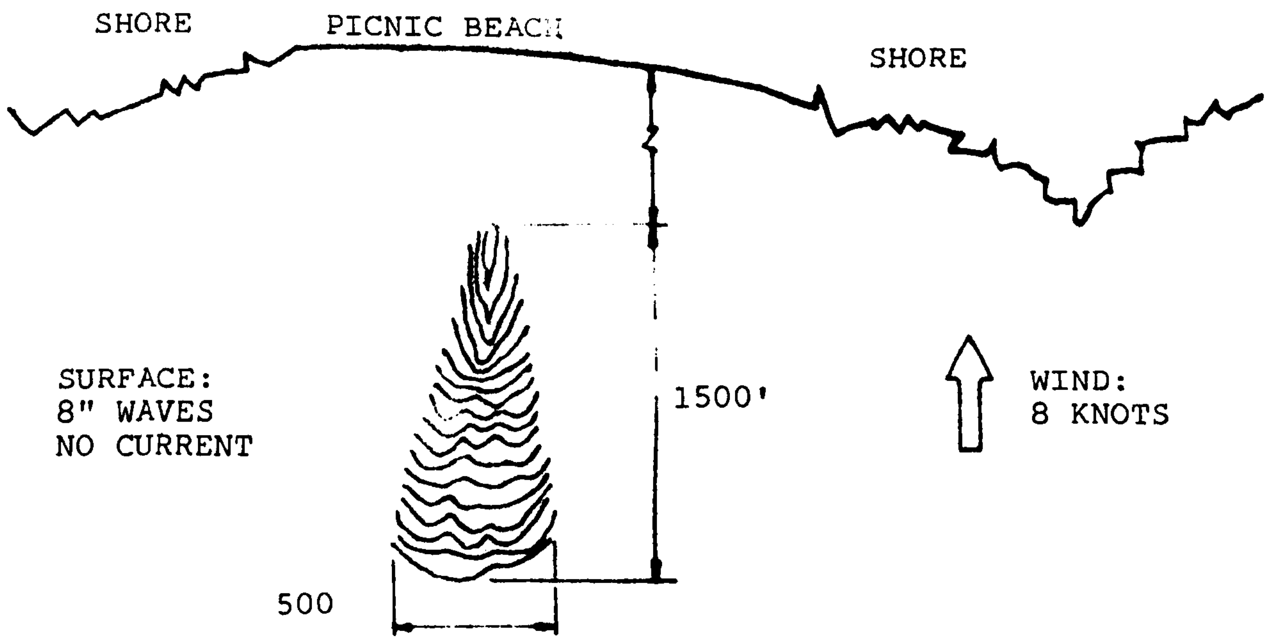
Back to the slick.

Where do you place your big skimmer? You have two choices, because you know that you have to take the skimmer to the oil or else bring the oil to the skimmer. Now you have a job for your oil containment booms.

Given the situation that is described, there are at least two ways to deploy your oil booms depending on the probable movements of the oil slick.

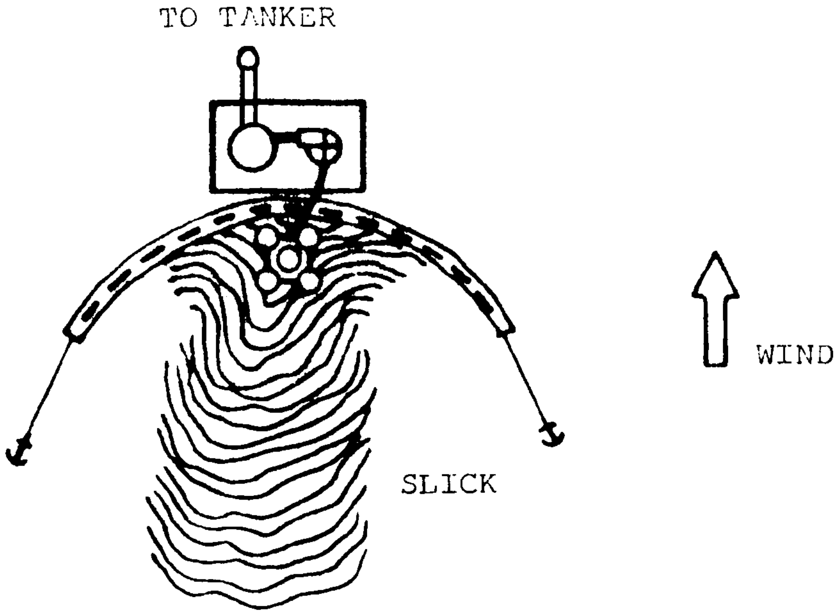
One plan is to contain the slick by putting a boom all around it, or by collecting the oil inside a loop of the boom. This means that you have to prevent any further movement of the oil. The other plan is to divert the flow of the oil to a point where you can skim it.

So you get out to the slick as fast as possible with your manpower and equipment and take a look at the slick. You find that the shape of the slick is now changing due to the wind, and the slick is about like this:



The slick is 500' wide and 1500' long. You have only 2000' of light, fence type boom. Not enough to go all around the slick. But you know the wind will probably continue to move the slick north. There are two ways to use the wind to your advantage.

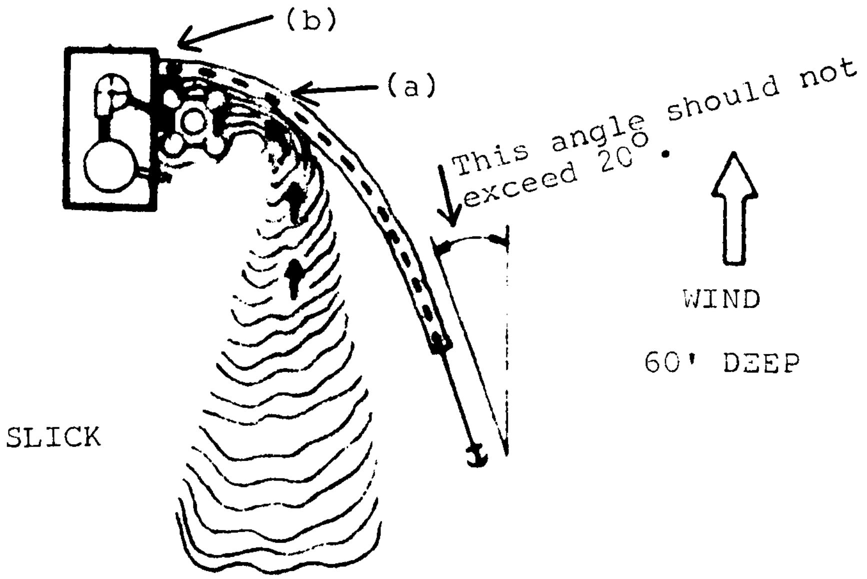
You might put 1000' of boom across the path of the slick and hope the wind will push all the oil into the arc of the boom. Then you could operate your big skimmer in the pool of oil which collects in front (upwind) of the boom, as shown in the next sketch.



If you elect this pattern, keep in mind that you are dependent on anchors to hold the boom in place, you have to hold your pump boat and skimmer in place against the push of the wind. You may have to keep a work boat inside the boom in order to hold the skimmer in place. If the wind changes you have a lot of moving to do.

A more flexible approach is to use your boom to divert the oil to your skimmer as shown on the following page.

Here you can hold one end of your boom close alongside the edge of the slick with an anchor or with a small boat. The oil will collect along the wind side of the boom and then will be diverted along that side of the boom to the skimmer. The skimmer can be held in position by making it fast to one side of your pump boat. As the slick arrives at the skimmer, the oil/water mix is pumped into the separating



tank on the pump boat and the clean water from the bottom of the tank can go back into the ocean <u>ahead</u> of the skimmer so that any oil which goes overboard will be picked up again by the skimmer.

To make this pattern work properly, be sure that you do these things:

1. There must be an oil-tight connection between the end of the boom and the entrance to the skimmers at (a), and another oil-tight connection at (b) between the skimmer and the pump boat.

2. Position of the up-wind end of the boom and of the work boat must be changed quickly as the wind shifts. The flow of the slick must continue into the area between the boom and the pump boat.

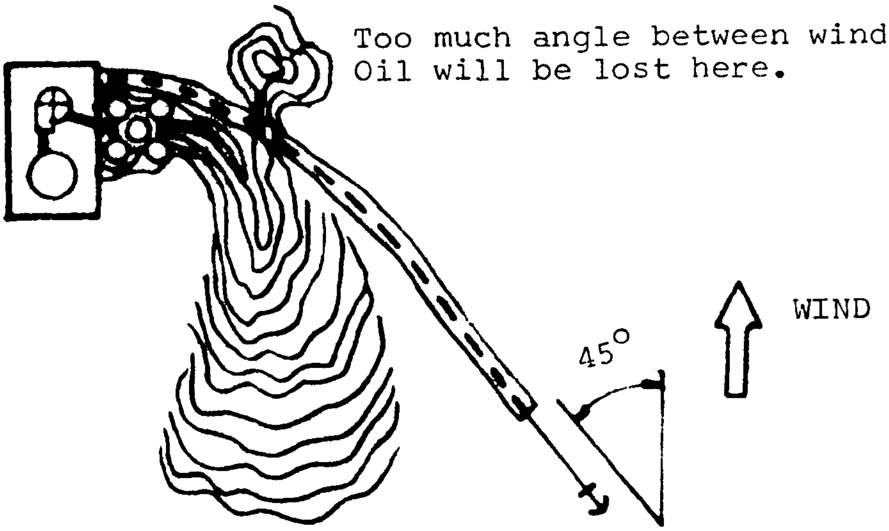
3. The pump boat must have enough tank capacity to handle the volume of oil/water mix coming from the skimmer. A 1,000 gallon tank would be minimum.

4. The skimmer must operate steadily, because there is not much area for a pool to form between the pump boat and the boom, and if this pool is allowed to overflow, oil will be lost under the boom or around the boat.

5. If a floating fabric tank or other vessel is available to receive the oil from the tank, that vessel should be standing by and ready to operate. It might be desirable to pump directly from the skimmer into the floating tank or vessel and let the separation process take place in that vessel or on shore.

6. The angle between the wind direction and the boom should not be greater than 20°. With more angle, the boom will tend to develop a belly in its shape and oil may be lost under the boom.

7. Be sure to have a good supply of gasoline or diesel fuel on a work boat to supply pump motors.

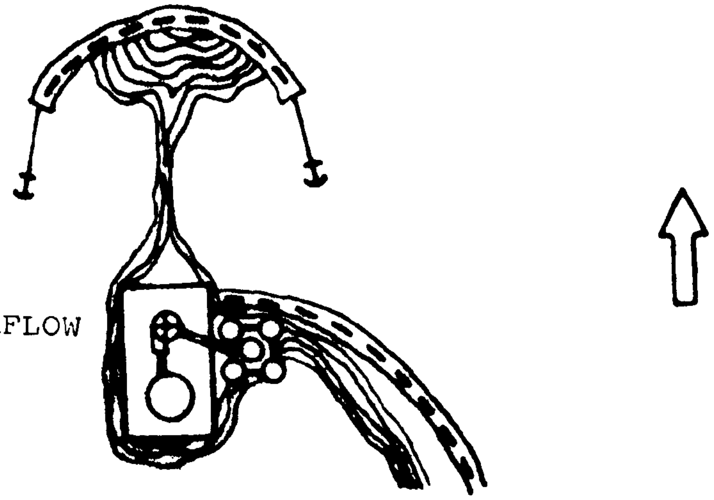


Now you have your diversion boom in position and the oil is beginning to arrive at the skimmer and going into the tank along with a lot of water. Maybe about 10 gallons of water to a quart of oil. Don't worry about the ratio of oil to water as long as your skimmer is taking the oil out of the water as fast as the oil arrives at the skimmer. The separating tank on the pump boat, or in the transport vessel (tank or barge or oil boat) or on shore will take care of that problem.

But if the oil starts to arrive at the skimmer faster than the skimmer can take it out of the water, oil will soon overflow around the pump boat or will pass under the boom and skimmer.

Now you still have 1000' of oil boom to use. You can rig another diversion pattern like the first and use the small skimmer. Or, you can use a containment pattern to hold the escaping oil.

The containment pattern might be better here, because your oil will be leaking from the overflow of the first skimmer, and it should be moving in a very narrow stream. Therefore you don't have to collect the oil from a wide area as you did with the first boom. You just need a big storage area to contain the leak until you get another skimmer into operation. So your second boom might look like this:



Overflow from the first boom system should be easy to hold with a short length of boom, perhaps only 200', because there will be a smaller volume, and it is already concentrated into a narrow stream. Get your second skimmer going in the smaller pool and hope that the combined capacity of the two skimmers is taking care of all the volume that your booms have captured.

Meanwhile, check back at the beach. Your crew at that spot has no boom to work with because you took it all out into Bounding Bay. But they might have use for a boom if you goof or if the wind rises and blows some oil past the booms feeding the skimmers.

So they get ready to provide moorings for a boom when it becomes available. Extra work? Sure, but remember the tourists will be here on the first warm, sunny day.

How do you place a boom to protect a beach? An inert barrier across the flow is not enough, because

1. If there is a lot of oil, the oil will go under the boom.

2. The oil might miss the boom by 50 feet and run around the end.

3. The boom is only a surface barrier. The best way to protect the beach is to get the oil out of the water and that requires a skimmer.....same remedy as out in

Bounding Bay. So you take these steps:

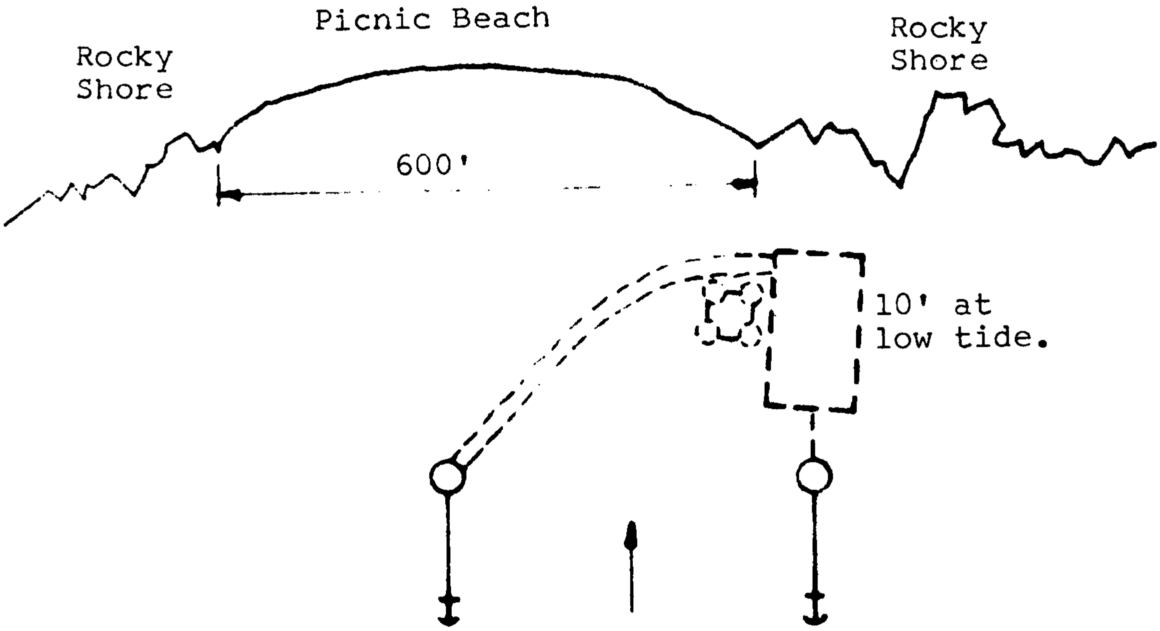
1. Choose an area near the beach where you can operate a skimmer.

2. Plan to put a diversion boom in front of the beach and outside the line of breakers to lead the oil toward the skimming area.

3. Place boom anchors at the proper spots so they will be ready for immediate use when you have some boom to work with. And place mooring anchors to hold the pump boat and skimmer in position when they become available.

4. In placing the anchors, set them solidly into the bottom, take care that each has plenty of ground chain and scope, and that the end of the scope is supported on a mooring buoy for easy pick-up when needed. And remember that there is a 12 foot tide in Bounding Bay and you don't want the pump boat moored where it will go aground at low tide. (And the moon will be full tonight and maybe you have a dreen low tide to contend with.)

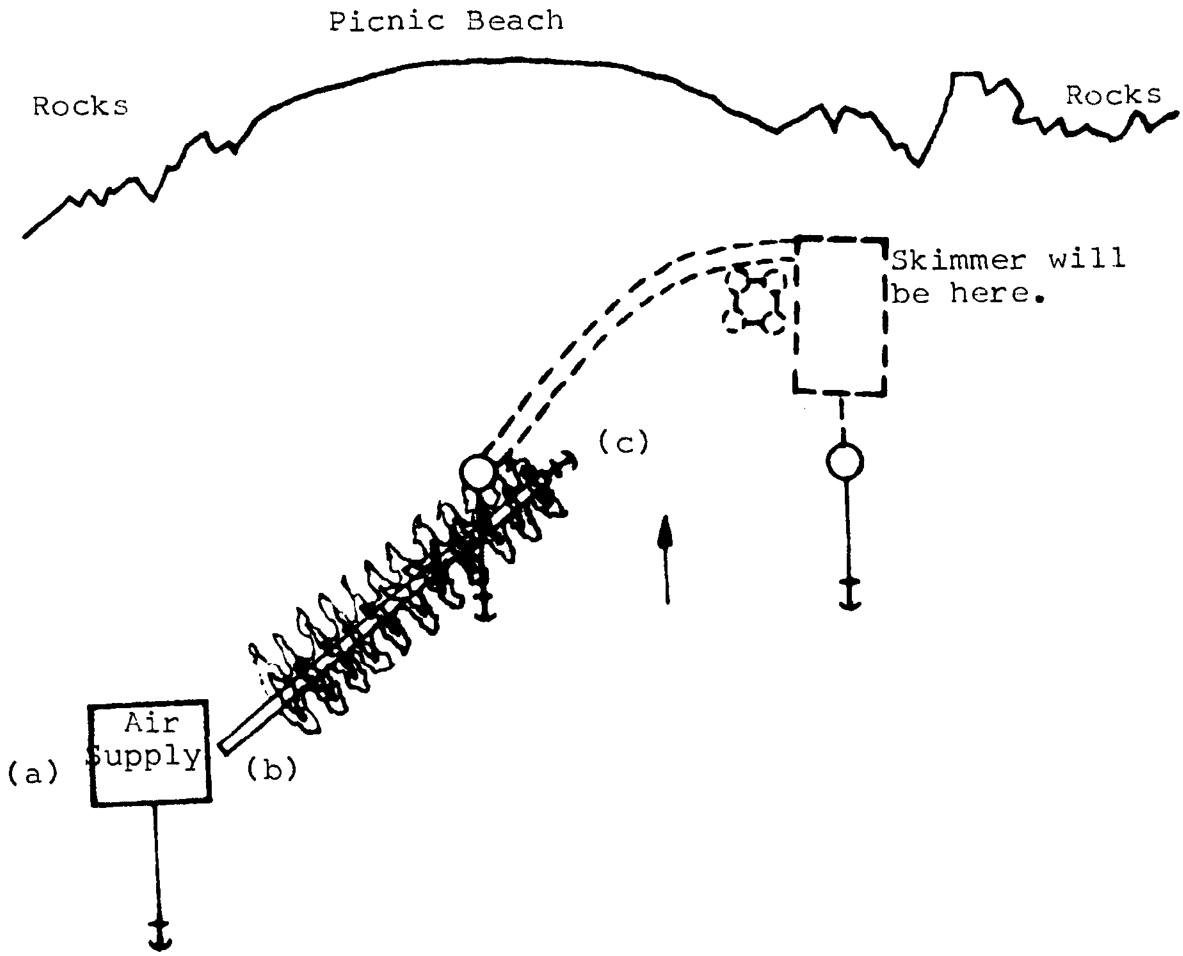
So your defenses at Picnic Beach may look like this:



But you only have 500' of boom available, and that is not enough to protect 600' of beach, particularly when you have to place the boom at an angle.

So you decide to use your air barrier to protect the end of the beach which you cannot shelter with the boom.

The air barrier is easy to place because it rests on the bottom. And don't worry if the bottom is irregular. If you have 8' of water over the air hose, the boil on the surface (the Z line) should form a solid line of effective surface current to divert the oil toward the boom and skimmer. The pattern would look like this:



The barge or boat with the air supply can be positioned as at (a). The air hose (weighted) can be deployed along the line (b), (c). At (c) the end of the hose should be anchored on the bottom and a buoy should be used to indicate its position.

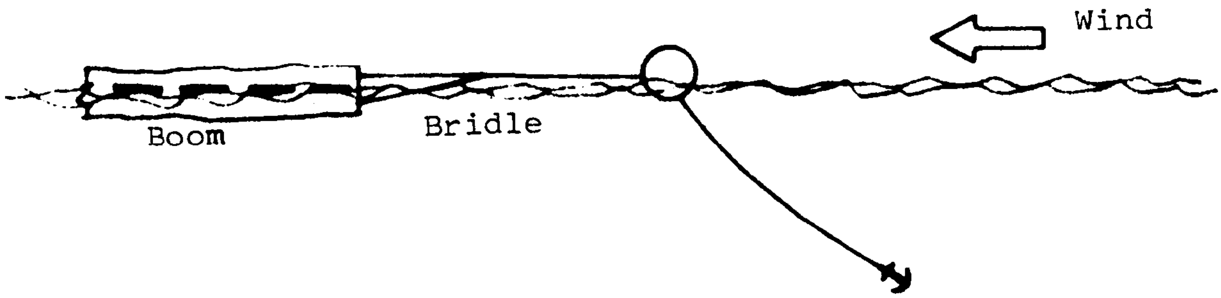
When the hose is in position, start the air supply and be sure the barrier pattern is properly formed and positioned. Some holes in the air line may need to be cleaned before the oil arrives. Do it now! When the barrier is working properly, put it on standby basis. Reduce the air supply to a minimum that will keep the holes from clogging. If you are equipped to pump fresh water or filtered salt water through the hose to keep the holes open, do so.

Now you are ready to put the barrier into operation as soon as the oil arrives and the boom and skimmer are in position.

So now you have your beach protected, and most of the oil is being picked up out in Bounding Bay. What can go wrong? Plenty. *And don't forget Murphy's law, which states:* "If anything can possibly go wrong, it will go wrong."

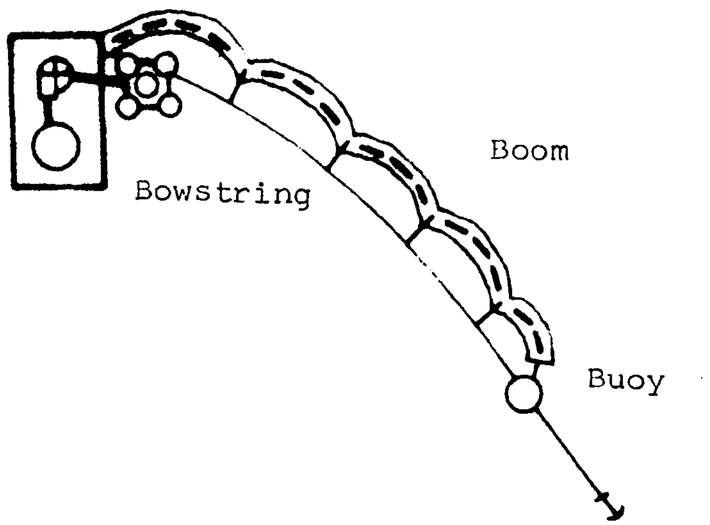
Here are some things to look out for:

1. When the first boom was positioned alongside the spill, the water was 60' deep. The wind did get stronger and put a lot of strain on the anchor rode. The rode, being at a downward angle, pulled the first fifty feet of the boom under water. The remedy was to put a mooring buoy on the anchor rode about 50 feet from the end of the boom. That tends to keep the pull horizontal on the end of the boom and reduce the chances of it's being pulled under. This is a side view of the anchor rode with a buoy.

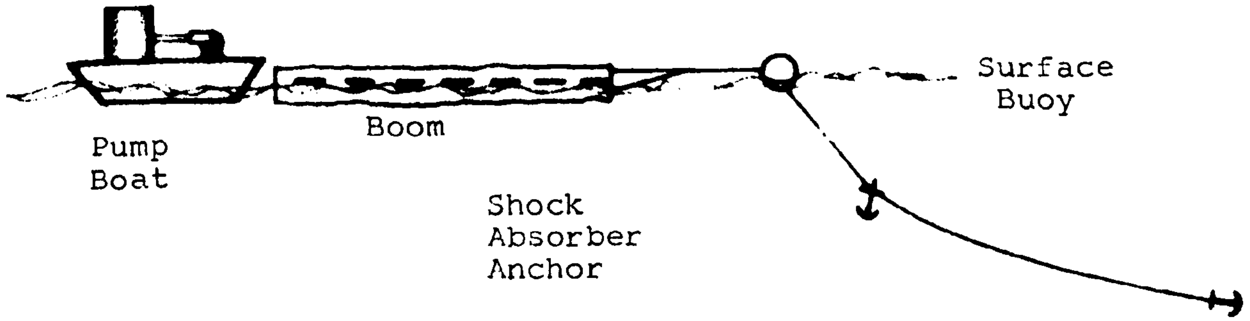


2. The strong wind generated waves 2 feet high. Normally, your fence boom would ride up and down on 2 feet waves without letting any water go over the top of the boom, but the strain on the boom tends to limit the flexibility of the boom in bending up and down over the waves. The fix for this problem is to put more buoyancy along the sides of the boom. If you are using the type of fence

boom which has clips where more floats can be attached, it is a relatively easy job. If not, or if the wave condition is causing continued spilling of oil, the strain can be reduced by using an extra line like a bowstring from one end of the boom to the other, with short lines from the bowstring to the boom at 30' intervals (more or less) to keep the boom in a pattern that looks like this:



3. If you placed the boom, when the tide was high, considerable slack will develop in the anchor rode as the tide goes lower, and this may let the boom drift out of position. If you have room to put out a long anchor rode, try suspending a small anchor or 20 pounds of scrap iron on the anchor rode halfway between anchor and surface buoy. This will tend to keep the anchor rode taut. The same type of arrangement, in very heavy waves or swells can serve as an effective shock absorber to minimize sudden strains on the line and its fastenings.



(Actually, you know all about these tricks because you have been lobstering for years, but some of the younger fellows and a lot of the tourists don't even carry a good anchor in their boat, much less know how to lower it overboard so the rode doesn't get tangled, or how to back down on it to set it firmly into the bottom.)

So your first spill is cleaned up (didn't even leak past the first skimmer) and nobody got dirtied and your equipment is all back in order and ready to go again if you ever need it. You never did find out who spilled the dirty bilge oil on Bounding Bay, but you took a sample to show the Coast Guard just in case they can analyze it and have some evidence.

Then two weeks later the phone rings again. Wakes you up at 2:00 a.m. on a foggy night. Local boatman just in from across the Bay. When he docked, he noticed a wide ring of dirty black oil around his white-hulled lobster boat. Guessed there must be some oil spilled out there somewhere, and thought you'd better know about it, and who is going to pay for cleaning up my boat, anyway?

The usual questions don't provide many answers. He didn't see anything or notice the oil when he went through it. What route did he take? Just South of Thrumcap Island. Came right past the spar buoy that marks the end of the ledge, he guesses (which means he was probably exactly where he said) but didn't see anything.

Wind from the North, beginning to blow a bit, expected to back toward North West by morning and clear out the fog. Tide just starting to ebb with current toward the South.

Someone in your office remembers that the weekly oil boat (the Magnolia from Garden City) from down East was due in tonight. Call her office on the 'phone and find out that she reported radar trouble two hours ago. Maybe she went aground on Thrumcap Island. Finally the ship-to-shore radiophone brings word that she did, she's keeled over to one side so that oil is leaking from her deck tank and the leak will continue until they get some mechanics aboard or until they get pulled off into deep water.

You alert the Coast Guard, call your team and send a boat out to explore. He reports an oil slick about six feet wide close to the stranded vessel, flowing to the South and beginning to break up into three or four separate streamers a few hundred feet from the wreck.

Now that you are an expert (because you have been through one spill successfully) you know that you must get your skimmers to work immediately. And the best place to work is close to the source of the spill where the slick is concentrated and as thick as it will ever be.

Now you are confronted with a continuing spill which will keep flowing until the source is stopped off, and you have no way of knowing how much quantity of oil will eventually leak out.

The only remedy for this situation is to get as much skimming capacity out there as you can so that you have capacity to pick up more oil than is flowing.

You dispatch your two skimmers with enough boom equipment to divert the oil stream to the skimmers and their pump boats. The storage boat follows along to take the skimmed oil to shore.

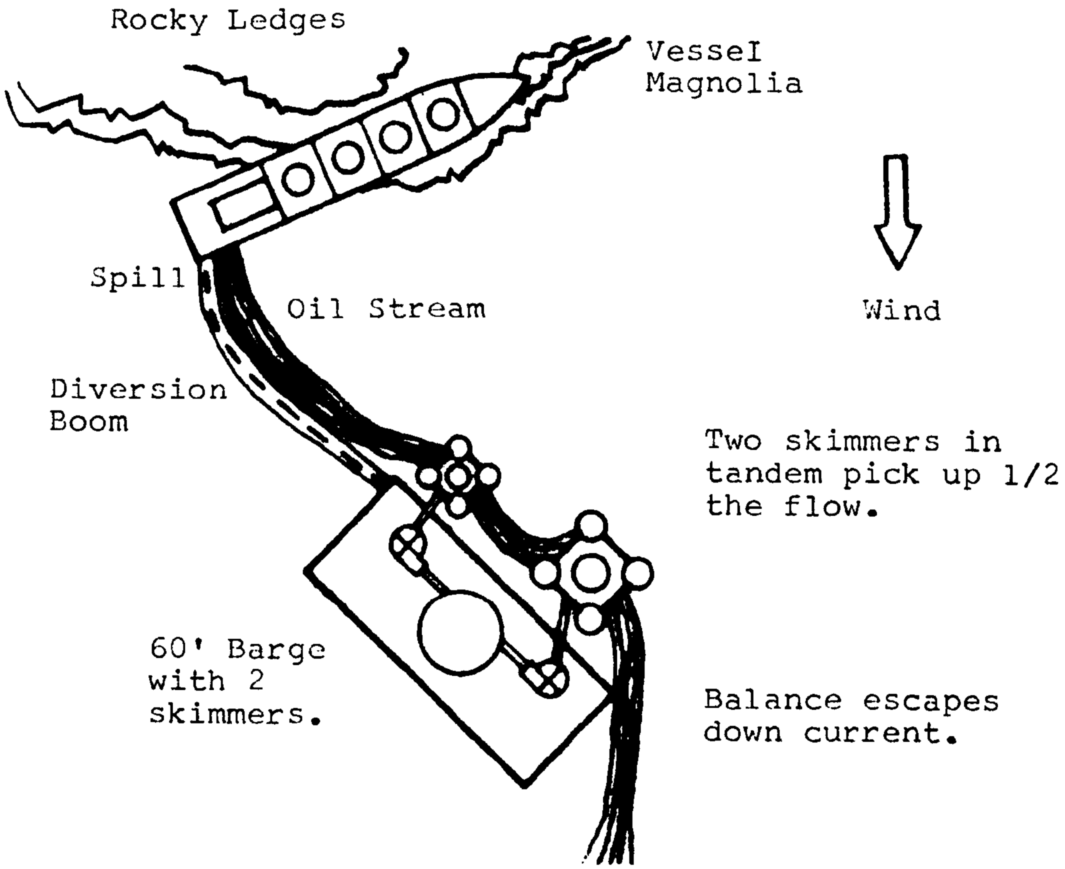
You want more equipment, so a call to Portland brings a promise of more booms and more skimmers by early morning. Also a crew to operate them and two more small tankers to help carry the skimmed oil to shore.

By dawn you are in business, with your two skimmers working fairly well, but able to get only half the flow of oil that is coming from the Magnolia.

So the pattern of your first skimmer operation might look like the sketch on the following page. This shows 2 skimmers positioned alongside a 50 foot barge which serves as a pump boat, and is big enough to support a 500 barrel tank for primary separation.

Note that you don't have to anchor the upwind end of the boom. Just make it fast to the stern of the Magnolia a few feet from the point where the oil enters the water.

(Note: every pattern of boom and skimmer operations shown in the previous sketches has been tested and proved in the testing portion of this Project. They work. The idea of putting 2 or more skimmers alongside one barge was tried out in the Louisiana spill. If the side of the barge is positioned properly with relation to the flow of the oil stream, the barge itself serves as a diverting boom and will permit the overflow from the first skimmer to pass to the next skimmer. The use of skimmers in gangs seems to be feasible. The skimmers will be most effective if they are moored alongside the barge so that they can rise and fall on the waves independently of the barge. This is a subject for further testing.)



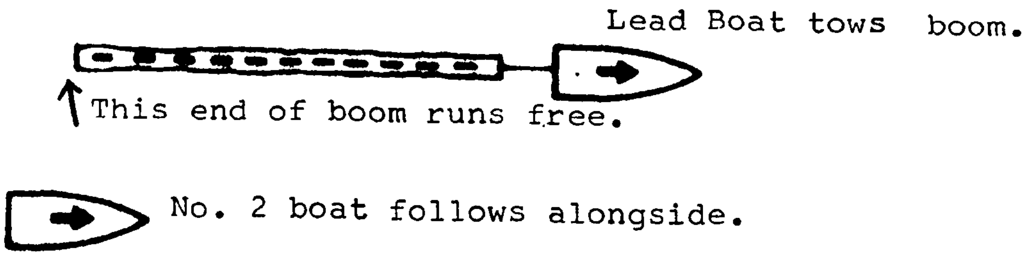
Now you need to know how bad the situation is down wind. How much oil has gotten away from the site of the spill and where is it headed?

You need an airplane or a helicopter. Get a report <u>from the air observer</u> and you can plan far better than on the basis of sea level inspection.

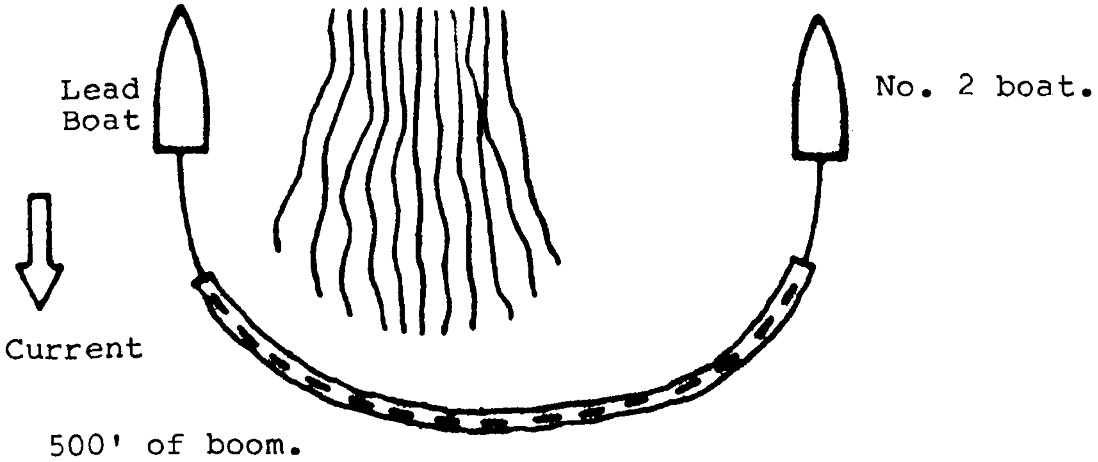
Fortunately, you find that very little oil escaped, and you can send two work boats to tow 500' length of boom between them and contain most of it about two miles down stream. You also send your beach patrol crew to plan for protection of any area which the oil might hit later in the day.

The two boats towing the boom can work in this kind of pattern:

A. On the way to the spill



B. At the area where oil can be collected



On arrival at the down stream end of the spill, the oil will probably be in several streams instead of one, and the streams may be widely separated.

The Lead boat starts up alongside one side of the pattern, and the #2 boat picks up the free end of the boom and tows it very slowly until the #2 boat is exactly abeam of the Lead boat, maintaining relative position just as accurately as possible. This takes a little practice, but it can be done.

By this means, the boom is pulled slowly against the current, and the oil will collect in the arc of the boom. Speeds of more than 1½ K relative to the surface of the water will cause leakage under the boom. Just hope that an additional skimmer can reach you soon enough to pick up the oil before the pool in the boom overflows or underflows.

If the boats are working into a current of more than 1½ K, you will actually be going backward in relation to the bottom of the ocean. By so doing, you keep your relative speed to the oil at 1½ K or less, and you keep the oil in the boom.

At this point the truck convoy arrives with more equipment. More booms and skimmers. You place the new skimmers where they will pick up the oil flowing past your own installations. You dispatch another new skimmer to help the tow boats with the boom down the bay.

Finally you have just about enough skimming capacity to take care of the flow from the stranded vessel, but if the tide goes much lower, she may keel over more and the leak will be greater.

At this point, the first small tanker arrives from Portland. If you can get her into position to pump out the oil cargo from the leaking tank, you will clean up a lot of oil before it even gets into the ocean.

Also, you find out that there is an empty hold on the vessel. Try putting a skimmer into the water alongside and letting it work where the oil first hits the ocean .....and pump that oil right back aboard the vessel into the empty hold. (And why didn't the Captain think of that? He did, but he didn't have a skimmer aboard. Maybe all tankers should carry some of their own oil clean-up equipment on board at all times. Another area for careful Research and Development.)

You also have help from a large skimmer boat that came in from Portland. It has a 200 barrel tank on board for primary separating, and deploys two skimming booms and two skimmers patterned after the skimmer boats used in the Louisiana spill. This boat is useful for patrolling various areas around Bounding Bay where small patches of oil have escaped from the booms, and in the course of the day, the skimmer boat cleans up every pocket of oil which the airplane or helicopter could find for her. Radio communication is indicated, but if it is not available between aircraft and skimmer boat, get some of the local lobster boats or cruisers to patrol the area and report via their ship-to-shore phones or on the working channel.

So by the end of the day, Bounding Bay is cleaned up, the leak on the Magnolia has been closed, and the Coast Guard has floated her. Your equipment is being repaired and cleaned ashore and made up for the next need. A lot of things were done right.

1. First of all, the attack on the spill started as soon as the location was even guessed. <u>No waiting for dawn</u>. (Sleep in the winter, after the tourists have gone home.)

2. The first skimmers on the scene went to work close to the source of the spill where the oil was thick and where the flow had not yet split into a lot of small streamers over a wide area.

3. Next, the attack was launched on every point that could be attacked:

   a. Skimming close to the source
   b. Skimming down stream
   c. Skimming alongside the vessel
   d. Skimming the random patches of oil which escaped from the booms
   e. Beach patrol was working at any probable point of impact of oil on shore
   f. The oil supply feeding the leak was removed
   g. Additional help was requested as soon as it was determined that the spill was a continuing spill. There was no waiting to estimate how much would be spilled, which is very difficult to calculate accurately unless the leak is coming from an orifice of known capacity.

Several things went wrong. (Nobody has repealed Murphy's law yet.)

1. The tow boats working down the bay needed more boom. Some of the spare boom from Portland was sent to them, but it was a different make and the end hitch didn't match the one on the Bounding Bay boom. The crew manufactured a quick hitch out of the oak slats from a lobster pot (and ate the lobsters when no one was looking) but they lost nearly an hour in the process. (The process of repairing the boom, not the eating.)

2. By 11:00 a.m. your best boom man had to go haul his lobster traps. By the time you got a replacement, one skimmer had been starved of oil for nearly an hour. (Remember, the booms are necessary to help the skimmers work effectively.) When the booms don't work, the skimmers can't work. And no booms ever took any oil out of the ocean. (Except that which sticks to them and is so hard to clean off that more attention should be given to the cleaning process. Maybe the man who sold you the boom should be asked to demonstrate how to clean it after the first spill!)

3. On the skimmer barge one of the pumps overheated and froze up. Unfortunately the discharge from the smaller skimmer had been manifolded into the discharge lines from the large skimmer so that there would be only one

pipe leading to the top of the separating tank. Back pressure developed in the small line and the pump had to be replaced. Each skimmer pump should have its own discharge hose into the tank. The pump has enough to do just to get the oil/water mix out of the ocean without having to fight another pump.) And the pump operation should have been thoroughly tested and proven long before this. (Dern it, can't think of everything.)

4. Early in the day, lots of work boats and sight-seers cruised back and forth ahead of the skimming booms and broke the slick up into a lot of small patches. This made the job harder for the two tow boats operating the sweeping boom. Get the Coast Guard to police the area and keep all non-essential craft out of the path of the working equipment.

Now you have cleaned up two spills, and you have a well trained crew, good equipment on hand and you know where you can get help if you need it.

The phone doesn't ring again for a long time. Maybe never. Maybe the science of transporting oil improves to the point that spills don't occur. Meanwhile, you keep in training, stay alert, learn to use the newer and better equipment that becomes available and you keep Bounding Bay clean.

Appendix D

COMMUNITY RESPONSE TO THE OIL SPILL PROBLEM

Formation and Operation of the Portland Harbor Pollution Abatement Committee

The Port of Portland in Maine is a major oil receiving port on the East Coast of the United States and it has the potential to become the largest mover of crude oil in the country. In 1968 the Port handled over 23 million tons of crude oil and more than 3 million tons of refined petroleum products.

Portland Harbor adjoins world-famous Casco Bay, one of the most beautiful boating areas in the world and a major center for Maine's Tourist Industry.

A group of citizens, concerned about the potential hazard from oil spills, organized the Portland Harbor Pollution Abatement Committee in 1966. Working in close cooperation with the Maine Port Authority, that Committee very quickly established a reputation for accomplishment in the Prevention and Clean-up of the "nuisance" oil spills which accompanied the petroleum activity.

By 1968 the Committee's program had produced the following results:

1. Establishment of a communication network to respond to an oil spill immediately with manpower and equipment.

2. Publication of an "Information Booklet on Oil Spills" outlining response and reporting procedures, key personnel, location of equipment and rules and regulations under which the committee functions. Two thousand copies were printed and distributed in answer to requests from all over the country and from oil ports throughout the world. The booklet has been used by other ports as a guide in organizing oil pollution abatement programs.

3. Extensive testing procedures on methods to move a "containment device" (boom) to the scene. Testing resulted in the design of a catamaran to store the boom when not in use and to play it out on the scene of a spill promptly and effectively.

4. Established procedures to react to a "mystery spill". This created the greatest problem to the committee, when oil appeared on the water in volume, and it was impossible to establish immediate responsibility.

5. Creation of a Data Bank on "oil pollution and abatement problems".

6. Construction of a helicopter pad on the waterfront to insure a more effective communication network to handle manpower maneuvers and to track oil spills in case of a major disaster.

7. The writing of an Oil and Hazardous Materials Contingency Plan for Prevention, Containment and Clean-up for the State of Maine was completed in January of 1970.

   Five hundred copies of the "Contingency Plan" were published on January 15, 1970 and within two weeks, demands completely exhausted the supply and a second order of 300 copies was delivered on February 15, 1970.

   The plan was written to assist the 115 coastal communities in Maine to prepare action in case of minor spills or a major spill effecting their community. It was known in advance, however, that others were interested in the State of Maine plan, and it has now become a model for both State and local level groups who are interested in developing their own programs. Those who wish a copy may obtain it by writing to the Portland Harbor Pollution Abatement Committee, 40 Commercial Street, Portland, Maine 04111.

   More details of the contingency plan appear later in this Section.

8. The Portland Harbor Pollution Abatement Committee is incorporated in the State of Maine.

As a result of the above program, Portland has established a world-wide reputation as a "tough port" where anti-pollution codes are strictly enforced. Tanker captains everywhere are passing word that, "When you're in Portland, be very careful about spills or you'll find yourself in a lot of trouble".

The project which is the subject of this report came into being partly because of the community support which could be depended upon to help meet the objectives of the testing program.

Community Reaction to the Testing Program

The project was activated in August of 1968 on the basis of a Federal Grant of $64,350 and "In Kind" contributions from the area of $36,500. The purpose of this project, as defined in the Contract is to "Test and evaluate oil booms and diffused air curtain bubble barrier for oil spillage containment and the design, construction and evaluation of oil recovery devices to remove the contained oil from the waters". Oil recovery includes the ultimate disposal of reclaimed oil and of sludge residues.

This project has generated a great deal of interest and active support among the residents of the 14 towns and cities near Portland Harbor and Casco Bay. The list of Acknowledgments in the report gives only an indication of the aid and assistance which was forthcoming from the area.

When help was needed it was immediately available. When a potential hurricane threatened the test basin area, a nearby filling station supplied a wrecking truck to pull expensive equipment to high ground. In February of 1970, when a "Nor'easter" with 60 mile winds drove booms and the articulated skimmer ashore on Fort Gorges Island in Portland Harbor, a lobster boat Captain took his boat into shoal waters so that project personnel could recover the equipment before pounding waves broke it apart.

These instances, and many others of similar nature, lead to the conclusion that the success of an oil spill clean-up capability depends in large measure on the support which the effort receives from members of the community it serves.

Consequently, the balance of this Appendix outlines the type of community effort which should be organized to assist in the procurement of equipment and the training of manpower to provide ancillary support for a prevention and clean-up program.

Objectives of a Community Effort

In order to function effectively, a community, company or organization must have an "orderly plan" that has as it's main objective, a program to prevent oil spills. When spills occur, as they may, then it is necessary to move into the second phase of the "organized effort", with a plan to contain, remove and dispose of the spilled oil.

As a proven example of an effective community effort, the following paragraphs outline the make-up of the Portland Harbor Pollution Abatement Committee, types of membership, operating procedures, funding, public relations and its communications network.

Membership

In Portland, Maine, the Portland Harbor Pollution Abatement Committee is a non-profit civic group comprised of the following: Industry (oil terminal operators, handlers, vessel owners, etc.), waterfront personnel (towboats, pilots, agents, etc.), city officials (city council, fire and police departments, public works, etc.), Chamber of Commerce, State Agencies (Port Authority, fisheries, environmental improvement, civil defense, etc.) and concerned civic and business leaders. It is important to have legal counsel on the committee. Portland has two categories of membership:

1. Regular members comprise those who contributed the original funds under which the committee is able to function, to buy equipment and commit itself to its objectives.

2. Associate Membership comprises that group who contribute annual dues. ($5.00 a year in Portland)

3. Membership is open to the public. The Portland Committee mails "notices of meeting" to over 200 people who have expressed an interest in the affairs of the committee. There are no paid employees, as each member contributes his time and expertise.

Operating Procedures

1. Portland Harbor Pollution Abatement Committee has adopted by-laws under which it operates (a copy of which will be sent to any group so requesting). The Portland Committee has filed its Charter within the laws of the State of Maine, therefore, is incorporated so that no member can be involved in any third party responsibilities in carrying out the objectives of the committee. Incorporation costs range from $300 to $500.

2. Officers and Directors must be elected, and it is suggested that the Chairman or President name a small executive committee (6 members) to function between meetings, and to make recommendations to the full committee.

Funding

In Portland Harbor the operators of the local oil terminals contributed the initial operating funds to the committee. The first contribution totaled $20,000.

Communications

An information booklet was published that has been most helpful in carrying out the objectives of the committee. (A copy of the Portland booklet as a guide is available upon request)

It includes the following subjects:

- Identity of the committee and its objectives
- Table of contents
- Listing of responsible parties to be called in the event of spill (phone numbers - office and home)
- Location of equipment
- Rules and Regulations on use of equipment
- Boundaries of responsibilities
- Phone numbers and locations of oil terminals
- Communication network (radio)
- Names of committee officers who have responsibility and chain of command

Equipment Policy

The committee owns some oil spill clean-up equipment and sets the policies and terms of its use. The equipment is handled by a local marine repair firm which has manpower and facilities available at all times.

Authority to call the equipment into use is delegated to Portland and South Portland Fire Chiefs, the Captain of the Port and designated members of the committee.

The location and availability of all other clean-up equipment and material is listed in the Contingency Plan for Portland Harbor. Thus, all equipment in the area can be marshalled readily in the event of need.

Organization of Community Support in the Clean-Up of Oil Spills

No approach to the clean-up of a major oil spill can be successful without proper attention to the assembling of manpower through a cooperative community effort. (Or through a company plan if the company is large enough to man and finance such a plan.)

If it is to be a community effort the leadership can be supplied by the local Port Authority, fire departments, civil defense head, or an industrial leader.

Man power should include:

City or Town Officials (Manager, Councilors, Selectmen)
Fire Chief - Police Chief
Representative from Water Quality Commission (State-Federal)
Civil Defense Head
Coast Guard
Ships Agents
Port Authority
Harbor Master
Oil Terminal Operators
Fishermen
Waterfront business interests (Pilot-Towboats, etc.)
Contractors
Organizations (Chamber of Commerce - Petroleum Industry
Audubon Society - Educational Institutions, etc.)
Conservationist
Civic Leaders

Following the formation of a cooperative group to direct energies and expertise to the problem, it is essential to establish responsibilities and chain of command for effective action in case of a spill. Suggested organization chart with responsibilities:

Chairman and Oil Spill Coordinator:

- Conduct meetings
- Oversee and Coordinate programs
- Act as spokesman to News Media
- Organize Public Relations
- Plan for Data Collection
- Set date for test exercises
- Plan for Research new equipment on market

On Scene Commander (Fire Chief, Coast Guard, Captain of the Port:

- On scene action
- Surveillance
- Policing
- Reporting
- Equipment responsibility
- Coordinate on scene Program
- Write and up-date contingency plan for port

Communications Commander

- Provide and up-date phone numbers of key personnel to be called
- Calling key personnel should spill require it
- Inventory of communication equipment (radios-walkie-talkies, etc.) availability, condition, repair, personnel and spare parts

Surveillance equipment available (Helicopter-fixed wing planes)
Establish Chain of Command response
Up-date instruction booklet

Supply and Inventory Control Officer

Publish and up-date complete inventory of equipment
Proper storage and maintenance
Replenish stock

Research and Reporting Officer

Keeps accurate records of casualty..writes it up and disseminates information to key personnel
Analysis performance, makes recommendation
Records conditions at time of spill
Provides "On Scene Commander" with weather conditions..ship traffic..manpower and equipment problems etc. types-capacities-number of ships visiting port

Training and Critique Commander

Arrange and coordinate plans for "test Exercises"
Provide charts and maps for location of key areas
Diagrams and plans of action
Write "problem and action" report
Provide "grid" map on location of oil terminals-fixed equipment-mobile equipment, etc.

Inspection and Equipment Reporting

Make periodic check of terminals checking facilities, equipment, communications, etc.
Reporting to committee

Communications Network

It is important to establish and maintain a complete communication network. This is to include radios, walkie-talkies, whistles, flags, bull horns and lights for morse-code signals.

Telephone communications are essential. In case of major catastrophe the communication network must call in outside help. This can be done through a planned program by telephone or radio communication.

Fiscal Responsibility for Oil Spill Clean-Up

A spill can take place at anytime. It is often easy to spot during the day by either ship or shore personnel. After dark strong odors on the site may give the first notice that a spill has occurred. In any event it is of utmost importance to the success of the "operation" to report the spill immediately to the responsible people to set the "clean up process" in motion.

This is an area that deserves and requires careful "advance" thought because the entire program can bog down at this point.

Because of the cost of cleaning up an oil spill, usually the work boat or clean up company must be assured as to who will pay the bill. It is therefore, important that whenever there is a call for "clean-up action" someone must be ready to accept financial responsibility.

If the spill is from a ship (with no direct oil terminal responsibility...that is a chartered ship to the terminal), the order for clean up should come from the Captain of the ship, or the ship's agent.

Experience shows that ship's captains and agents have been reluctant to accept financial responsibility for the spill. When there is more than one ship in port engaged in transferring petroleum products the problem is compounded.

In Portland Harbor, the PHPAC accepted responsibility to pay for ordering out the clean-up crew should there be any delay in determining responsibility. With some funds in their treasury the committee knowingly opened up what could be a pandora's box of financial responsibility, but took the action in an effort to protect the community and environment for any hesitation in "reporting a spill", and accepting responsibility.

Fortunately and with credit to the petroleum carrying industry, hesitation in accepting responsibility and reporting now seems to be more of the exception then the rule. It must be recorded, however, that this has been a problem in the past, and does still remain a potential problem and communities must be alerted to it.

The problem has been recognized by the Congress, which is presently moving to make some part of $35,000,000 available for clean-up of those spills where responsibility remains undetermined. The State of Maine is proposing a bond issue of $4,000,000 for similar purposes.

Conclusions

A well organized community group, dedicated to the prevention of oil spills always and to immediate and effective clean-up of oil spills when they do occur, is the best guarantee of continued progress in the controlling of oil pollution on navigable waters.

Appendix E

A CLEAN-UP SYSTEM FOR MAJOR OIL SPILLS

Discussion of Available Resources

At this writing it is evident that considerable progress must be made in the development of technology and the readying of equipment in order to minimize or prevent damage from a major oil spill.

It is true that one major spill was handled in Louisiana in March of 1970, but there were fortuitous circumstances involved which have not been present in other spills. Furthermore, the technology which was successful in skimming crude oil in Louisiana would not have handled the congealed Bunker C oil at Chedabucto Bay in Canada in February, 1970.

The time factor at Louisiana permitted the building of 32 high volume skimmers before the spill reached major proportions. Today, that skimming equipment may still be available in the Louisiana-Texas area, (it has indeed been used on at least one other spill near Galveston) but major logistical problems would have to be overcome to make that equipment effective at any great distance.

A gradual build-up of equipment is noticeable in many petroleum terminal areas and operational spills are being handled more effectively every year, but there is no evidence of any marshalling of massive equipment at strategic locations except in Louisiana to guard against the dangers of a major spill.

However, among Federal programs already under way, the Coast Guard has reported successful testing of off-loading equipment (pumps and floating storage tanks) to remove cargo from tankers at the site of a spill. The Coast Guard will have prime responsibility for manning stations where this equipment will be stored.

A major task of this project is to outline a feasible system to be used to combat major spills. The following paragraphs of this section contain specific recommendations for such a system. The recommendations include specifications for equipment and suggestions for its use, as well as basic operating policies which must be observed.

Basic Operating Policy No. 1.

Removal of spilled oil (skimming) is the essence of the entire system.

There are two basic skimming techniques which have been proved successful. The circular weir suction skimmer removes an oil/water mix from the spill area. It is simple to operate, relatively inexpensive, maintains some effectiveness in very rough water and can be used in multiple units to develop massive capacity. It is most effective on crude oils and light weight oils.

The endless belt (or revolving disk) skimmer has been reported effective in removing viscous oils (Bunker C) in the Chedabucto Spill in Canada under winter conditions which made the oil too sticky to flow through the orifices and suction hoses of a weir skimmer.

Basic Operating Policy No. 2.

Successful clean-up operations require sufficient skimmer capacity to handle the volume of oil spilled in the time available.

A skimming operation must deal with two types of major spill. There is the finite spill, wherein the source of the spill can be shut off quickly and the volume of oil spilled can be measured or predicted with reasonable accuracy. There is also the continuing spill wherein the flow of oil may go on indefinitely.

For example, when a tanker ruptures two cargo holds, it is probable that the spill will not exceed the contents of the two damaged holds. The volume of clean-up capacity required can then be determined, making due allowance for the time available for such clean up before storms or other conditions make operations difficult or impossible.

In a continuing spill such as Santa Barbara or Louisiana, the rate of flow can be estimated, but the duration of that flow may be unpredictable. In such case, skimmer capacity having a clean-up rate greater than the rate of flow is a definite requirement.

Basic Operating Policy No. 3.

A clean-up operation should attack a spill at every point where clean-up or additional prevention can be effective.

In a continuing spill, skimmers should operate as close to the source as possible in order to skim the oil where the film is thick enough to make for easy skimming and where a minimum of booming or compacting is required.

At the same time, other skimmers and containment or diversion booms should be operating at points distant from the spill where the oil slick has spread over a wide area or has separated into a series of ribbon-like slicks.

Furthermore, booms should be placed to protect sensitive areas threatened by the approach of a slick and skimmer operations should be placed and ready to operate at those points when and if oil begins to accumulate.

Basic Operating Policy No. 4.

Time is of the essence. None of the clean-up operations should be delayed because of legal wrangles over responsibility for the spill.

It should be a function of government to provide the necessary authorization for immediate clean-up to take place while such clean-up can still be effective. (On a small scale, operations of the P.H.P.A.C. have overcome this problem by authorizing immediate action in emergencies and providing for determination of responsibility and settlement of claims at a later date. See Appendix D.)

Basic Operating Policy No. 5.

The basic equipment for clean-up (skimmer, boom and storage capacity) should be readily available at all strategic points where oil spills might occur.

The strategic points include oil terminals where oil is on-loaded or off-loaded, tank farms and bulk stations located near the ocean, lakes or rivers, and on board every tanker carrying petroleum products.

As regards tankers, consider the case of the Torrey Canyon, aground on the Scilley Isles with several holds broken open. If she had been able to drop two high capacity skimmers into the oil slick alongside those leaking holds, she could have skimmed a lot of oil out of the ocean and held it on board even in the ruptured tanks until additional help arrived.

Obviously, as oil leaks out of a ruptured tank, storage space is available at the top of the tank. An oil/water mix skimmed from the slick alongside and pumped into the tank would find temporary storage. The water in the oil/water mix would tend to migrate to the bottom of the tank and go out of the break before the oil would follow. Valuable time could be gained and every bit of oil recaptured even temporarily would represent a net gain in the clean-up of the whole spill.

Skimmer Capacity

The capacity of the circular weir skimmer used in Louisiana was limited only by the capacity of the pump connected to it. Thus, a skimmer working with a 4" pump of 440 gpm capacity had a through-put of 440 gallons per minute of liquid.

Pumping in a deep pool of oil, the capacity to pump oil would be 440 gpm. Pumping in a slick, the capacity to pump liquid (an oil/water mix) would still be 440 gpm, but the volume of oil would depend on the oil/water ratio in the slick.

In some thick slicks, ratios of 60% oil to 40% water have been noted. In slicks where the oil has spread into a very thin film, ratios of 10% oil to 90% water are more usual. Consequently, capacity of the circular weir type of skimmer is best expressed in terms of through-put of liquid.

A separating skimmer, such as the endless belt design or the multiple disc design separates oil from the water at point of removal, and very little water, if any, accompanies the oil.

In this case, the theoretical capacity of the skimmer can be expressed in terms of oil removed per time interval. In practice, however, the theoretical capacity is only reached when oil is present in sufficient volume to keep the discs or belt loaded to their maximum at all times.

Operating in a very thin slick, this type of skimmer would suffer from lack of oil and its actual output would be substantially below theoretical capacity.

System Capacity

Ideally, the capacity of a clean-up system should be equal to the total capacity of the skimmers involved.

All other equipment should have capacities equal to or greater than that of the skimmers. Otherwise, the skimmers cannot be used to their maximum capacity. Inasmuch as the skimmers are the most essential equipment in the system, they should never be compelled to operate at less than optimum capacity. Pumps, transfer hoses, storage tanks, separating systems and transport vessels must be made available in sufficient volume to keep the skimmers going at optimum capacity. Otherwise, the system will not deliver its intended volume and the clean-up effort will suffer.

The Ultimate Size of Skimmer

As tankers grow larger and pose the possibility of massive spills, the supply industry tends to think in terms of massive skimmers to counter the threat.

Beyond a point, however, size can become a liability because such size may boost purchase price and operating cost to the point that very few units would be built and availability would be limited. Size may generate mechanical problems during rough sea operations, highly trained crews may be required (and stand-by costs for such crews are considerable) and big equipment may not be operable in many bays, harbors, estuaries and shallow water areas where massive spills might penetrate.

The immediate alternative is to design skimmers so that multiple units can be worked in gangs where large capacities are needed, just as gang mowers are used on a golf course, multiple combines are used to harvest wheat fields or dozens of pumpers are used at major fires to provide the massive through-put of water.

On the basis of present information, circular weir skimmers and pumps having a through-put capacity of 800 to 1000 gpm might provide an optimum compromise of all factors. Used singly, they would be readily portable by truck, boat or plane. In groups of 2 or 3, they would provide capacity to handle most of the spills which have been recorded, and several gangs could be used simultaneously if greater capacity were needed.

Conclusions

1. The type of equipment described above has been proved to be effective up to the limits specified.

2. Basic clean-up systems built around the equipment specified would constitute effective systems to the limit of their capacities. (Equipment should include both weir skimmers and belt or disc skimmers.)

3. Individual systems, as described, would provide effective clean-up capacity, adequate for many locations where small spills might occur.

4. High mobility of the individual systems would permit quick concentration of multiple units to combat massive spills.

Recommendations

1. Pending the development of major advances in technology, units as described should be placed at strategic locations throughout the United States.

2. Action should be initiated to install such units (or the essential elements thereof) on all tankers operating on routes where land based equipment is not close at hand.

Appendix F

AERIAL PHOTOGRAPHY OF OIL SPILLS

The aerial photography of the controlled oil spills in the inner harbor at Portland, Maine was performed by Singco Division of Montvale Industries Corporation. One purpose of this mission was to provide a photographic record of field operations at the test site. A controlled oil spill was contained and harvested with appropriate test equipment. Another objective was the aerial photographic determination of oil-slick phenomenology and the relationship of the detection process to aircraft search and tracking operations during accidental spills on ocean waters.

The photographic emulsions for the aerial missions were infrared film (black and white) and color film to be exposed simultaneously. The use of dual or multi-spectral bands in optical discrimination systems can be effective when the signals from the separate channels are analyzed jointly. Color film can record subtle changes in hue. The fact may provide additional dimension of information beyond the capability of ordinary panchromatic film. In order to provide a basis for comparison, it was decided to use high speed panchromatic film as the third test emulsion. Further, advantages of near real-time processing of black and white film has operational significance.

Infrared film (black and white) is sensitive out to 850 millimicrons into the near infrared region of the spectrum. Ordinary panchromatic film cuts off near 650 millimicrons in the visible red. The use of infrared film in the photography of terrestrial or marine scenes is based on the differences in reflectance of solar infrared radiation by earth features. Such features at terrestrial temperatures do not emit enough infrared radiation to be detectable by infrared film at a wavelength of 800 millimicrons. Energy emitted by them at earth temperatures falls at wavelengths 10 times as distant on the wavelength scale. Conversely, a heated flatiron in a dark room would have to have a temperature of several hundreds of deg C to be recorded on infrared film.

Instrumentation

A Cessna Light aircraft was instrumented with equipment to perform the aerial photographic mission. A camera mount was designed and constructed for use off the port side of the aircraft. Three cameras are mounted along the same line-of-sight at an angle adjustable from about

30 deg to 60 deg from the nadir. The Nikkorex Auto 35 camera system is used with a trio of Nikkor H,F:2, 48-mm lenses and with a 85-mm telephoto conversion lens and a 35-mm wide-angle conversion lens. Exposure settings may be either automatic or manual.

The camera system is flexible and convenient allowing adjustments in field procedure and in the choice offilm emulsions.

Aerial Photographic Mission of October 9, 1969 At Inner Harbor, Portland, Maine

The spillage, containment, and clean-up of a 100 gallon spill at the field site in the inner harbor at Portland, Maine was recorded from the air.

Takeoff at Bedford: 1045 EDT
Return to Bedford: 1700 EDT
Weather: Clear skies, light surface winds from NW veering to the E in the afternoon, calm seas, visibility unrestricted.

Flight Procedure Over Site: Elliptical pattern at an altitude of 800 ft. view angle of 45 deg; exposures were made at an aircraft heading of 130 deg from North with the sun at an azimuth of 90 deg from the aircraft nose (to starboard) increasing to 120 deg at the end of the photo mission. Photographs were recorded during the period from 1300 to 1507 EDT.

Kodak infrared film (IR 135) and Kodak Tri-X Pan film were used to obtain the black and white photographs in this mission. A No. 25 red filter was used with the infrared film and a No. 15 yellow filter was used with panchromatic film.

Figures 1 through 7 are selected photographs showing the progress of the operations at the test site as recorded on two black and white emulsions. Evaluation and description of the appropriate features of the photos are presented under figure captions.

Application of Aerial Photography to the Detection and Tracking of Controlled Spills

The aerial detection of oil spills on the high seas poses a different problem when the location and the extent of the spill is unconfirmed or unspecified. Operational requirements of an aircraft search and scan mission will be concerned with target detectibility, background and false alarm discrimination, resolution at the ocean surface, optimum altitude of flight, scantechniques, and photo interpretation. Determination of these factors can only be arrived at by investigating oil spills of significant amounts on the high seas under conditions approximating those that would be realized in an operational mission.

From the results of the photographic mission under clear skies over the harbor at Portland, Maine, some conclusions can be made which are reasonably extrapolated in the direction of the larger problem.

Visual detection of the thick black oil spills easily made with the unaided eye by an observer aboard the aircraft from an altitude of 1,000 ft. under fair weather illumination conditions. The appreciable oil-to ocean contrast can be recorded with panchromatic film (Kodak Tri-X Pan Film) with a No. 15 yellow filter to reduce atmospheric haze. The oil strongly absorbs the visible light and the turbidity of the marine background reflects enough radiation to provide a brighter background. Overdevelopment of the film during processing can accentuate the contrast. The use of this panchromatic film is useful to record the main denser portions of an oil spill.

Ocean waters are typically very dark on infrared film (Kodak IR 135) because of the high absorbtion of the near infrared by ocean waters. Thick oil spills are similarly strongly absorbing so that their contrast with the marine background is only marginally detectable. However, in later stages when the oil film is of molecular thickness, infrared film is capable of bringing out the detail of the oil structure as it diffused and transported in the water. Such structure may be invisible with other emulsions as can be seen by comparing the IR and Tri-X photographs. The brighter structure of the thin oil film is in all probability associated with optical interference at the interface. It is not clear at this time whether other contaminants in the water (algae or other pollutants) would present interfering signals, and there is some evidence of this. Shape discrimination will be useful in this respect. (Exhibit 27.)

Infrared film are generally of slower speed and care must be taken to insure sufficient exposure in order to capture reflectance differences on water surfaces as the light levels of interest are of low magnitude. Since the desired detail falls close to the limits of the emulsion, overdevelopment during film processing is recommended. Infrared film is used with a red filter (No. 25 or 89) to eliminate the blue light to which this film is also sensitive. This film-filter combination is especially useful in viewing through atmospheric haze. With both films, photo evaluation or photo interpretation can be more suitably done by viewing the positive transparencies with transmitted illumination and an optical aid.

The effect on the foregoing of adverse conditions of illumination has to be further investigated. The infrared content of sunlight is deteriorated under cloudy skies and the effect of atmospheric haze through long slant paths will also be unfavorable.

Note: This is an unedited report as received from Singco Corp. The Grantee on 150-80-DOZ is not responsible for content or conclusions expressed therein.

CORE SAMPLES OF AN OIL SPILL

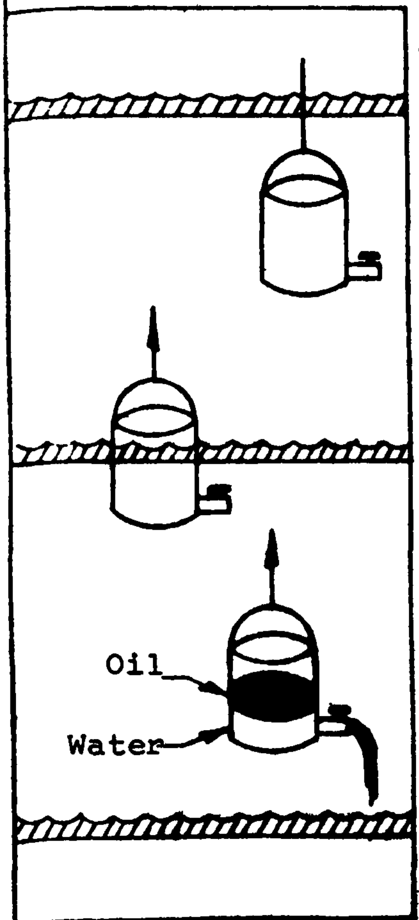
Objective: to generate basic information on type of oil and quantity spilled.

Program : to develop a method of taking "core" samples at the site of a spill

a. From surface craft
b. From aircraft

: to develop preliminary tests of the core samples to indicate type of oil, volume, thickness of spill.

Procedure: Core samples can be taken at the site by using a conventional 6 gallon pail equipped with a drain valve at the lower end.



1. The pail should be immersed so that top is well below the lower edge of the oil slick, and with the valve OPEN.

2. Pail is slowly raised so that rim of pail cuts through oil slick and emerges above surface. Water below oil slick inside pail drains out of the open valve while the pail is being raised.

3. Pail is raised clear of the surface and valve can be closed while clear water is still in bottom of pail below the oil sample.

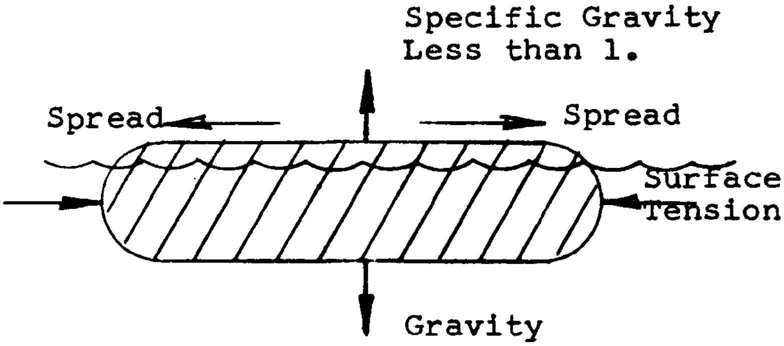
4. Pail with valve closed and a tight cover in place can be transported to laboratory for analysis. Analysis can be both quantitative and qualitative.

Note: On the Singco Project Test, this procedure was followed and quantitative tests were made by chloroform extraction procedures.

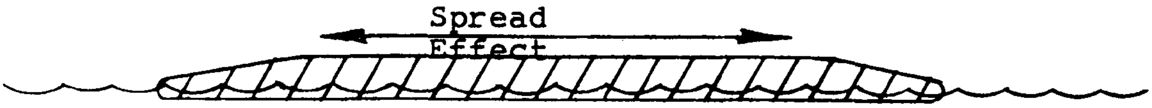
Exhibit 1.

FORCES ACTING ON AN OIL SPILL

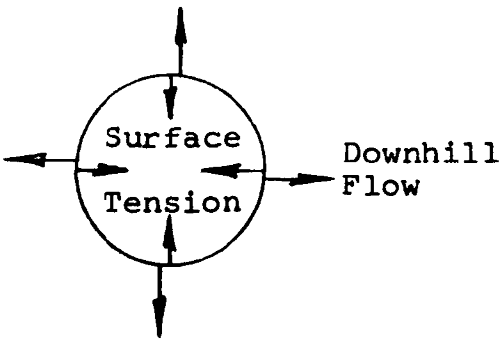
Forces Affecting Position in the Water
(Assume Wind Zero and Current Zero)



Sectional View as Oil Droplet Surfaces.

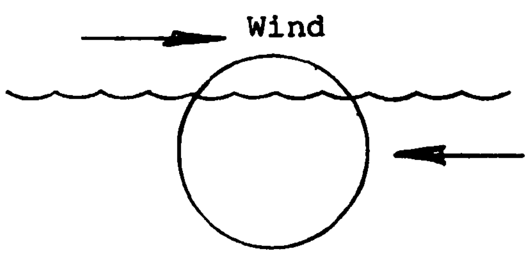


Sectional View after Spread Effect takes place.



Plan View of Forces at Surface.

Forces Affecting Travel Through the Water



Section of a Thick Spill.

Force exerted by sub-surface current due to river flow or tidal action.

Section of a Thin Spill.

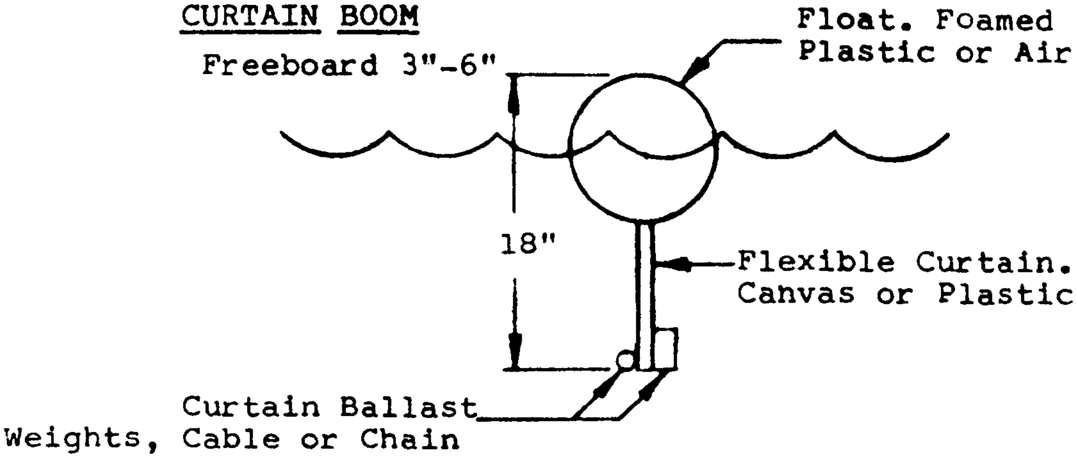
Maximum area exposed to wind effect.

Exhibit 2.

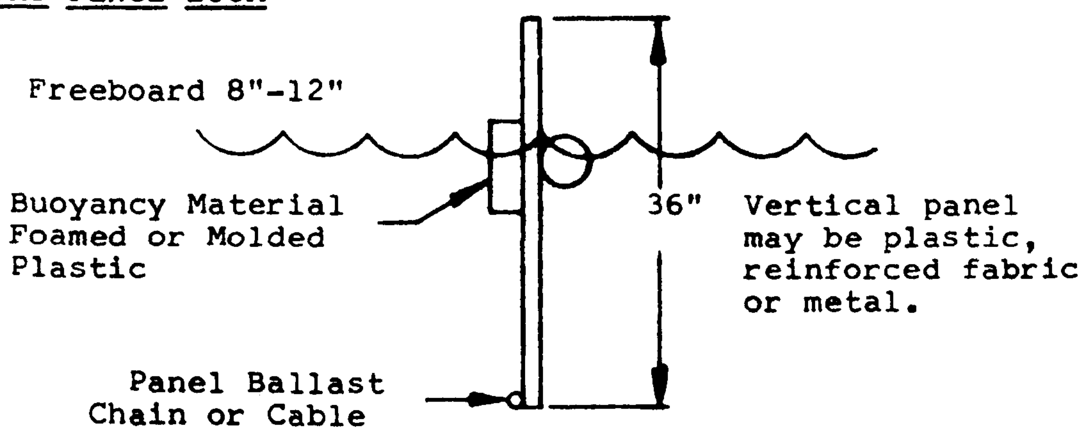
TYPICAL BOOM DESIGNS

(Vertical Sections Across Boom)

CURTAIN BOOM



LIGHT FENCE BOOM



HEAVY FENCE BOOM

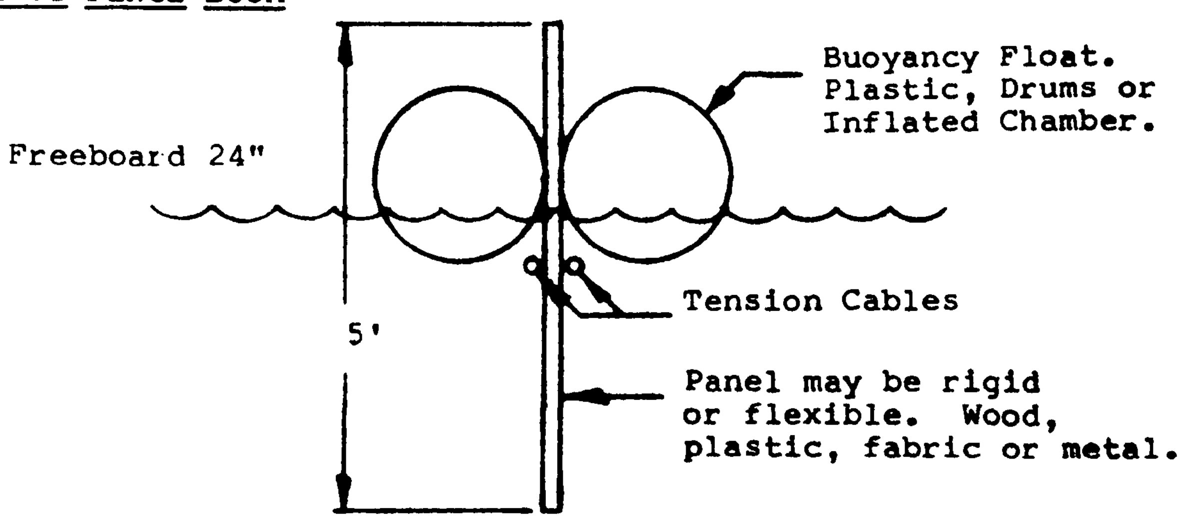


Exhibit 3.

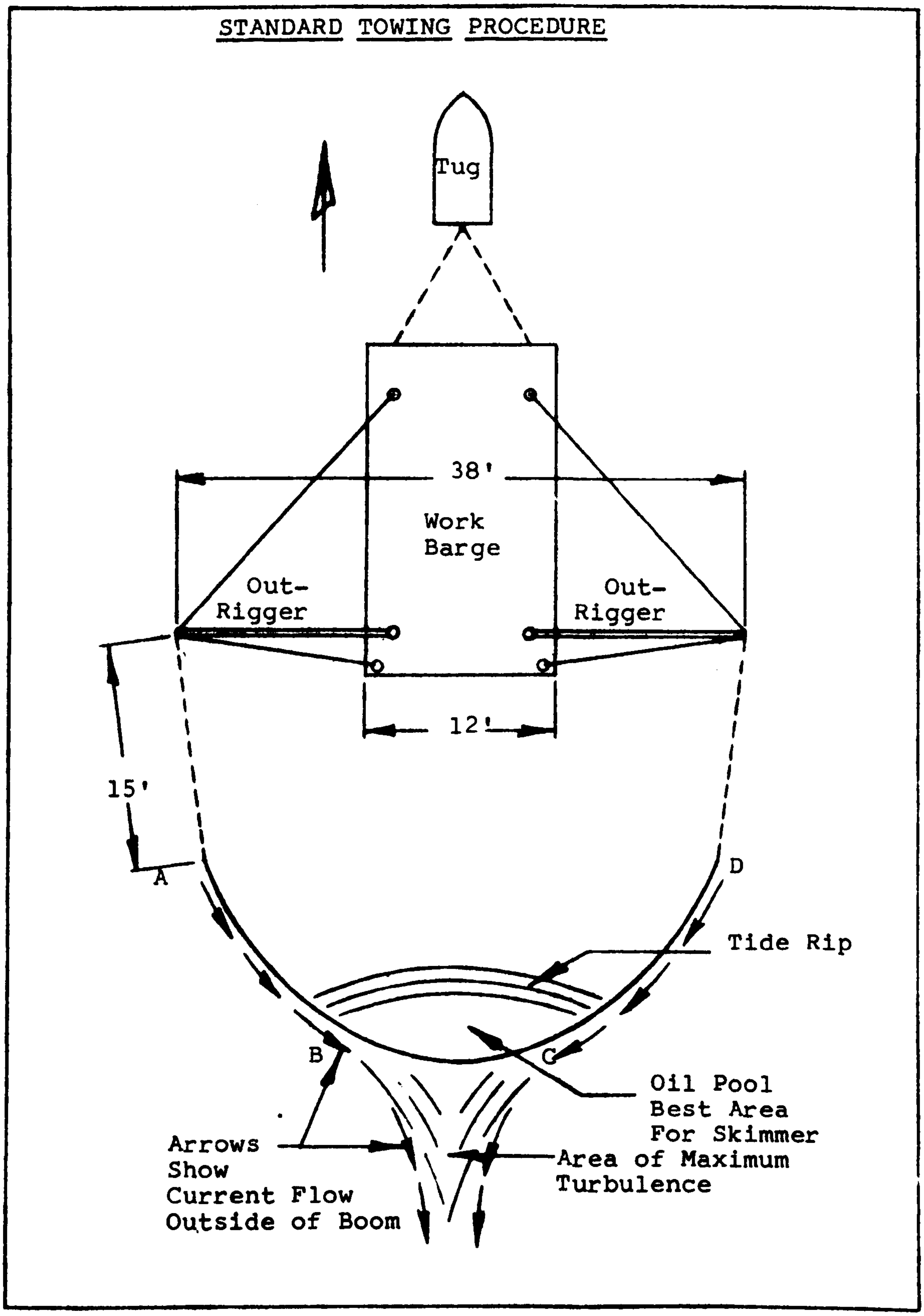

STANDARD TOWING PROCEDURE
Tug
38'
Work
Barge
Out-
Rigger
Out-
Rigger
12'
15'
A
D
Tide Rip
B
C
Oil Pool
Best Area
For Skimmer
Arrows
Show
Current Flow
Outside of Boom
Area of Maximum
Turbulence

Exhibit 4.

CURRENT PATTERNS UNDER A FENCE BOOM

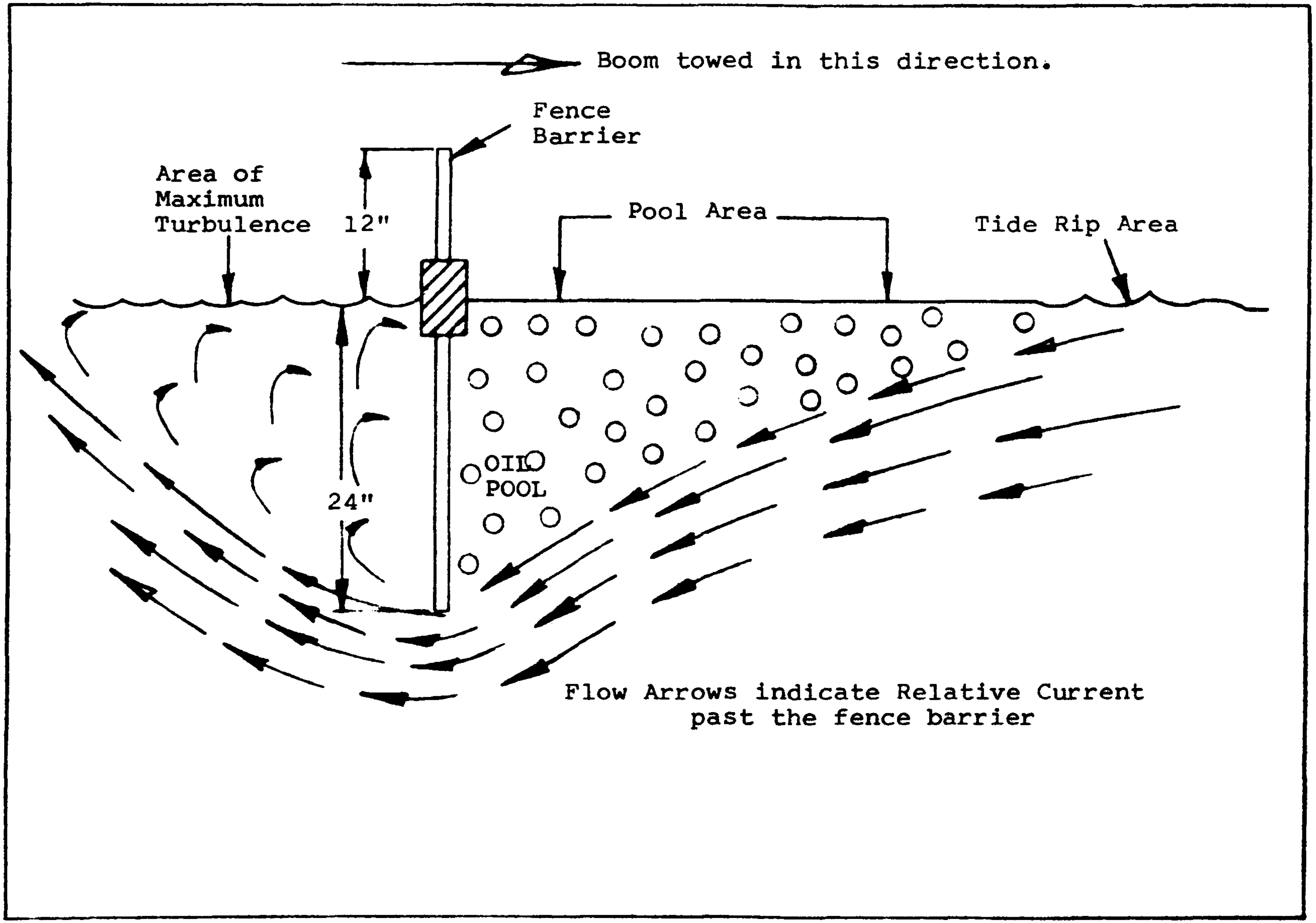
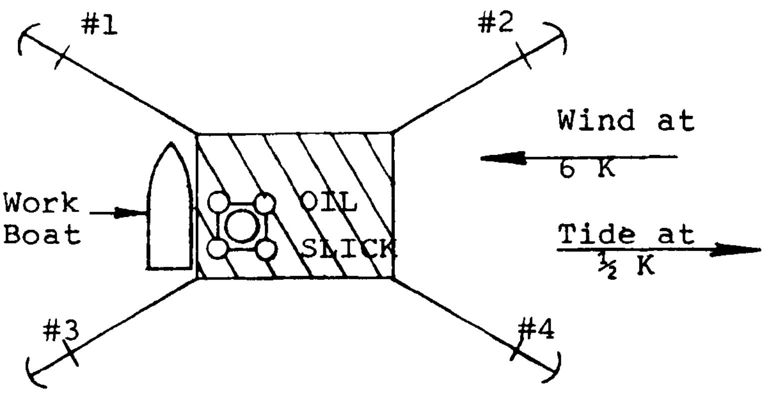


Exhibit 5.

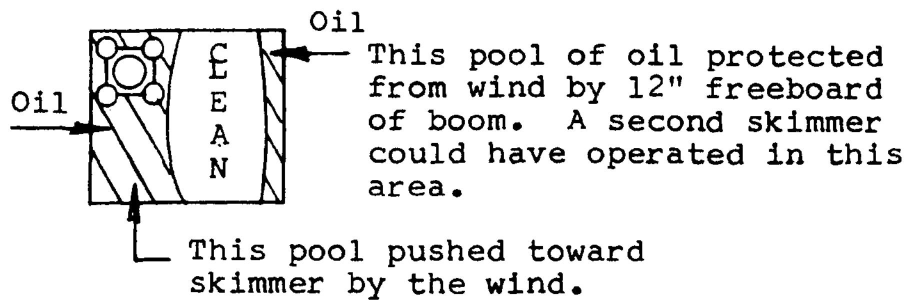
MOVING OIL INSIDE A BOOM
TO COMPACT THE CONTAINED OIL

Procedure used during Singco Project test of October 9, 1969.

1st Observation - 200' Offshore at start of Skimming process.



2nd Observation - Oil Slick coverage after 10 minutes of skimming - result of wind



3rd Observation - Boom re-rigged by slacking mooring lines #2 and #3 and shortening line #1.

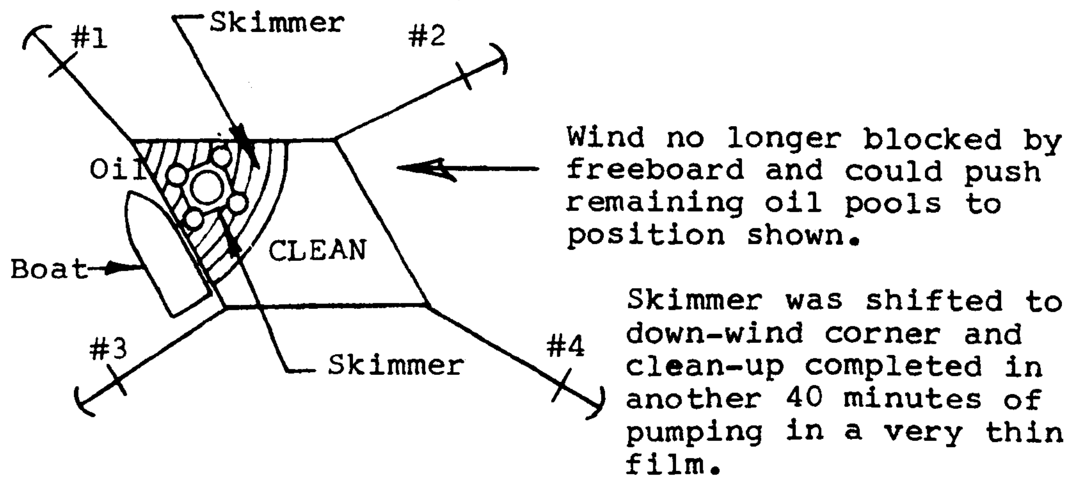


Exhibit 6.

TOWING A FUNNEL BOOM

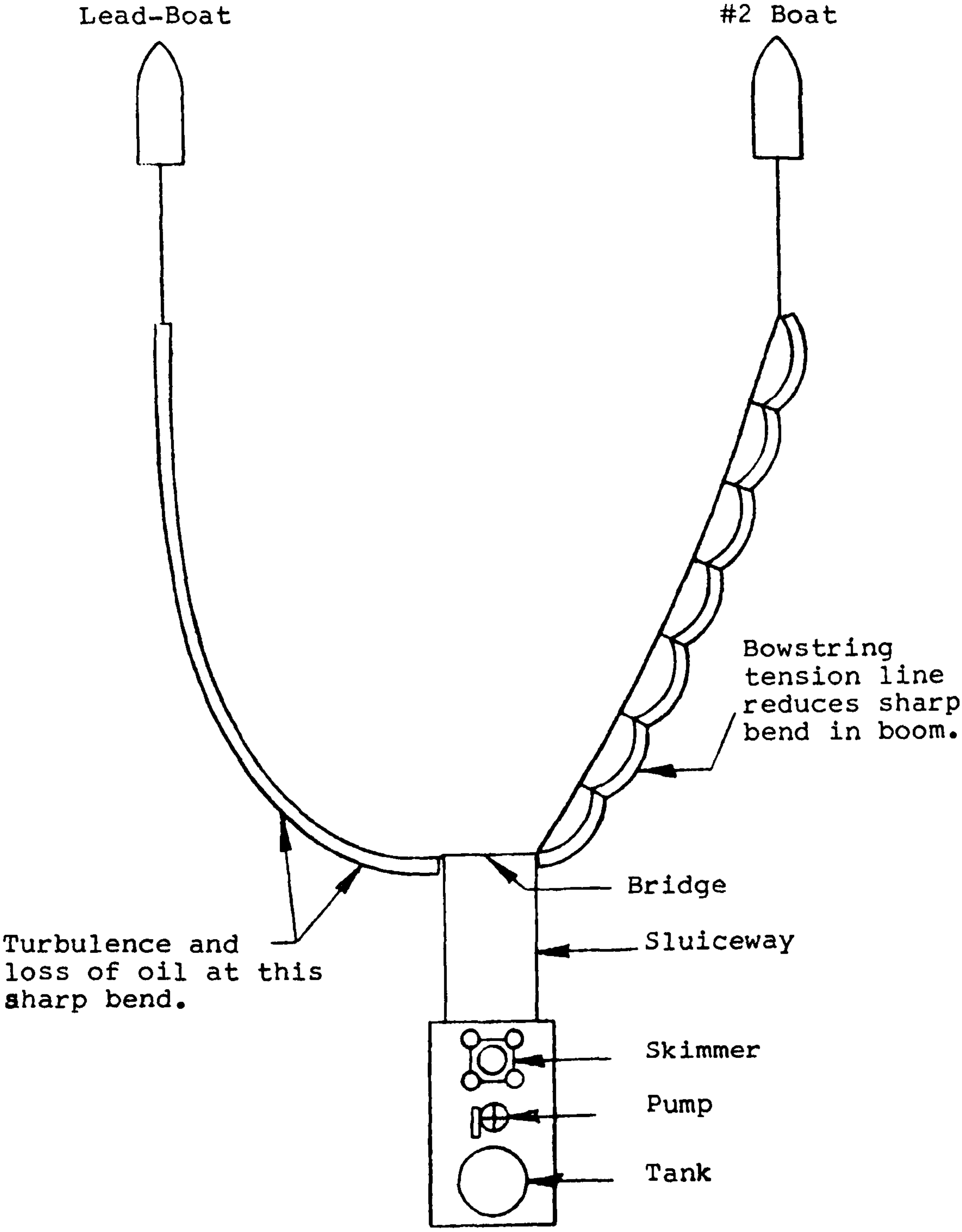


Exhibit 7.

DIVERSION BOOM TEST

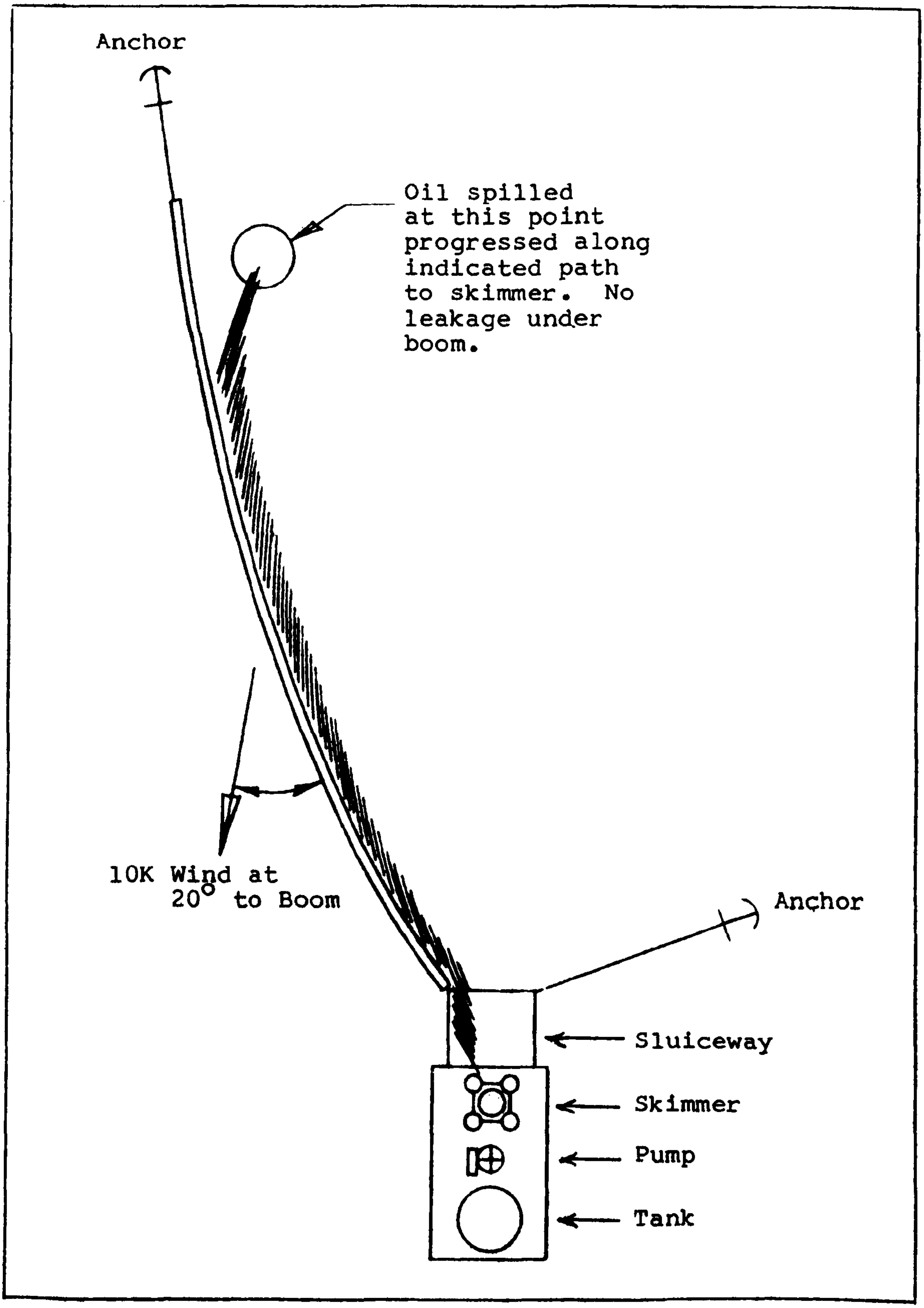
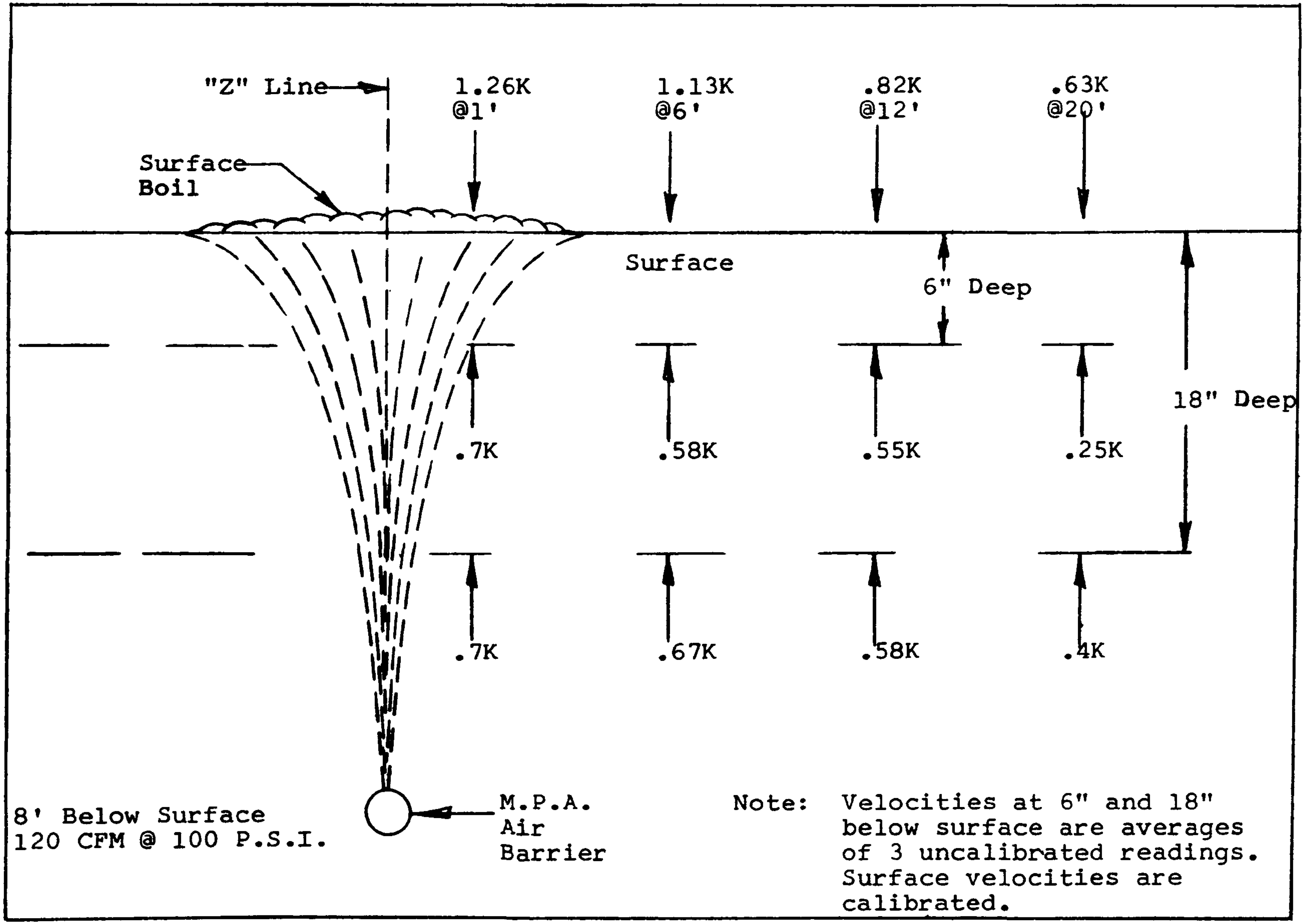


Exhibit 8.

CURRENT VELOCITIES NEAR AN AIR BARRIER



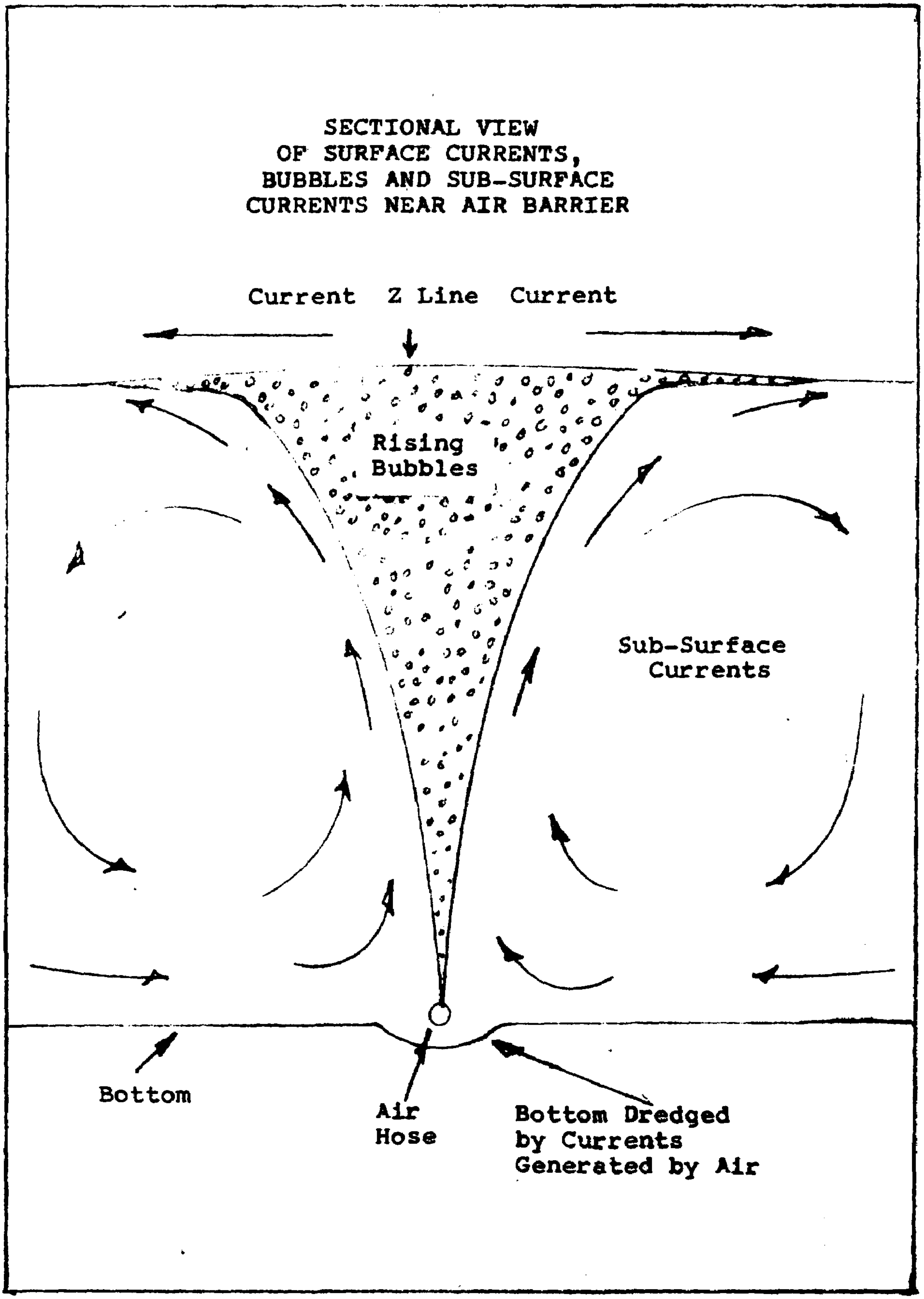
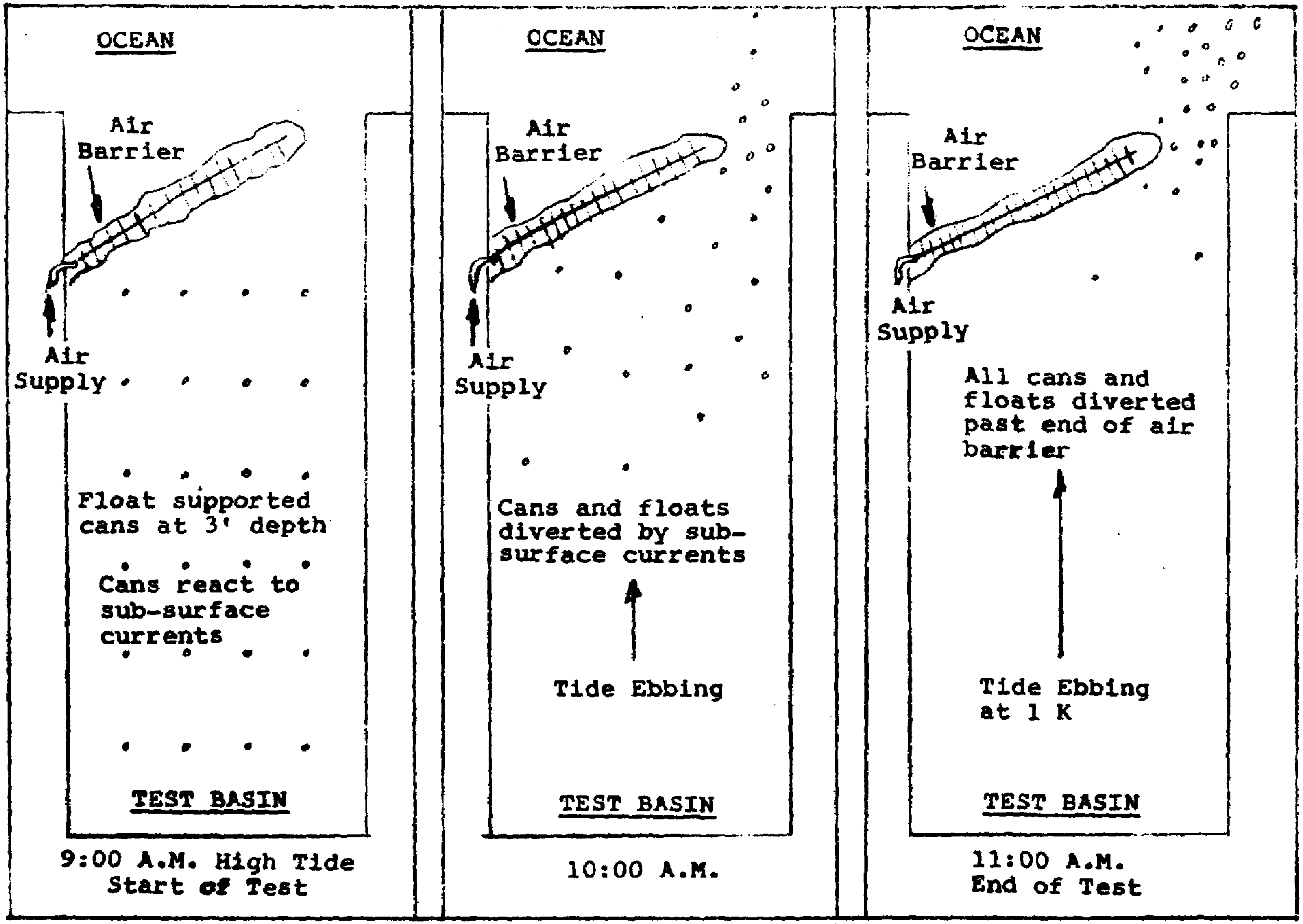

SECTIONAL VIEW
OF SURFACE CURRENTS,
BUBBLES AND SUB-SURFACE
CURRENTS NEAR AIR BARRIER
Current
Z Line
Current
Rising
Bubbles
Sub-Surface
Currents
Bottom
Air
Hose
Bottom Dredged
by Currents
Generated by Air

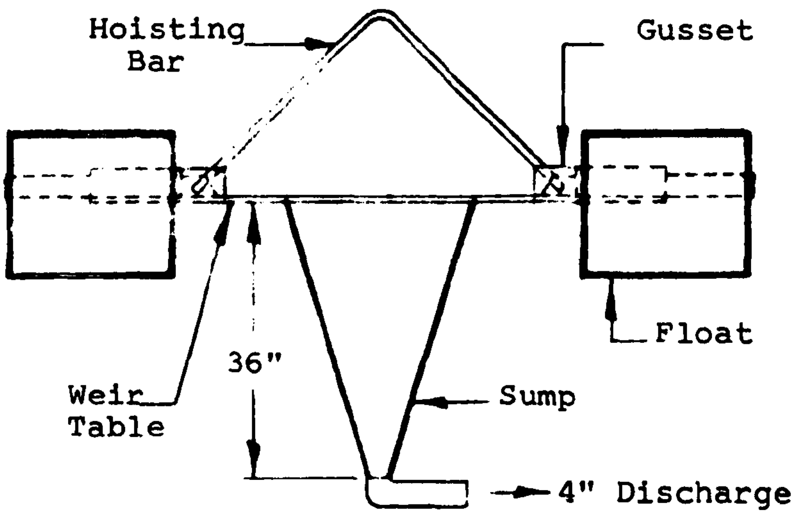
Exhibit 10.

Exhibit 11.



Diversion Effect of
Sub-Surface Currents in an Air Barrier

THE AK SKIMMER DESIGN



SECTION A-A'

PLAN VIEW

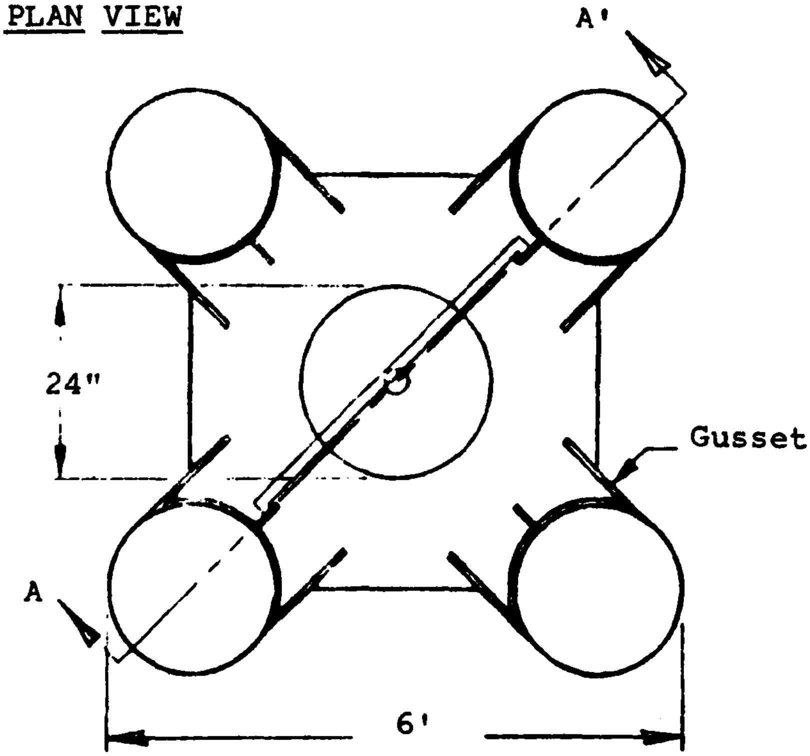


Exhibit 12.

PAGE NOT

AVAILABLE

DIGITALLY

22 Skimmer Designs Studied in this Project

Identification:

"Separating" Skimmers

- "Oilivator" Endless Belt
- Golten Endless Belt
- Dutch Shell Oil Scrubber
- Welles Rotating Drum
- Amoco Rotating Drum
- "Mop-Cat" Rotating Drum
- Earle System
- Golten Rotating Drum

"Blotter" Skimmers

- Johns-Manville Sea Serpent
- Arabian Poly Mattress
- Absorbent Float (Unidentified)

"Suction Nozzles"

- Vacuum Tank Nozzles
- Golten
- Slickbar Manta Ray

"Separating Column" Skimmers

- Norfolk Navy Yard
- Slick-Sled
- T.T. Skimmer Boat

"Floating Weir" Skimmers

- Hammerli Agricoles, S.A.
- Shell Experimental
- Acme (Sunshine)
- A.K.

Articulated Skimmer

- Designed for this project

Exhibit 14.

ARTICULATED SKIMMER (PROPRIETARY-U.S. GOVT.)

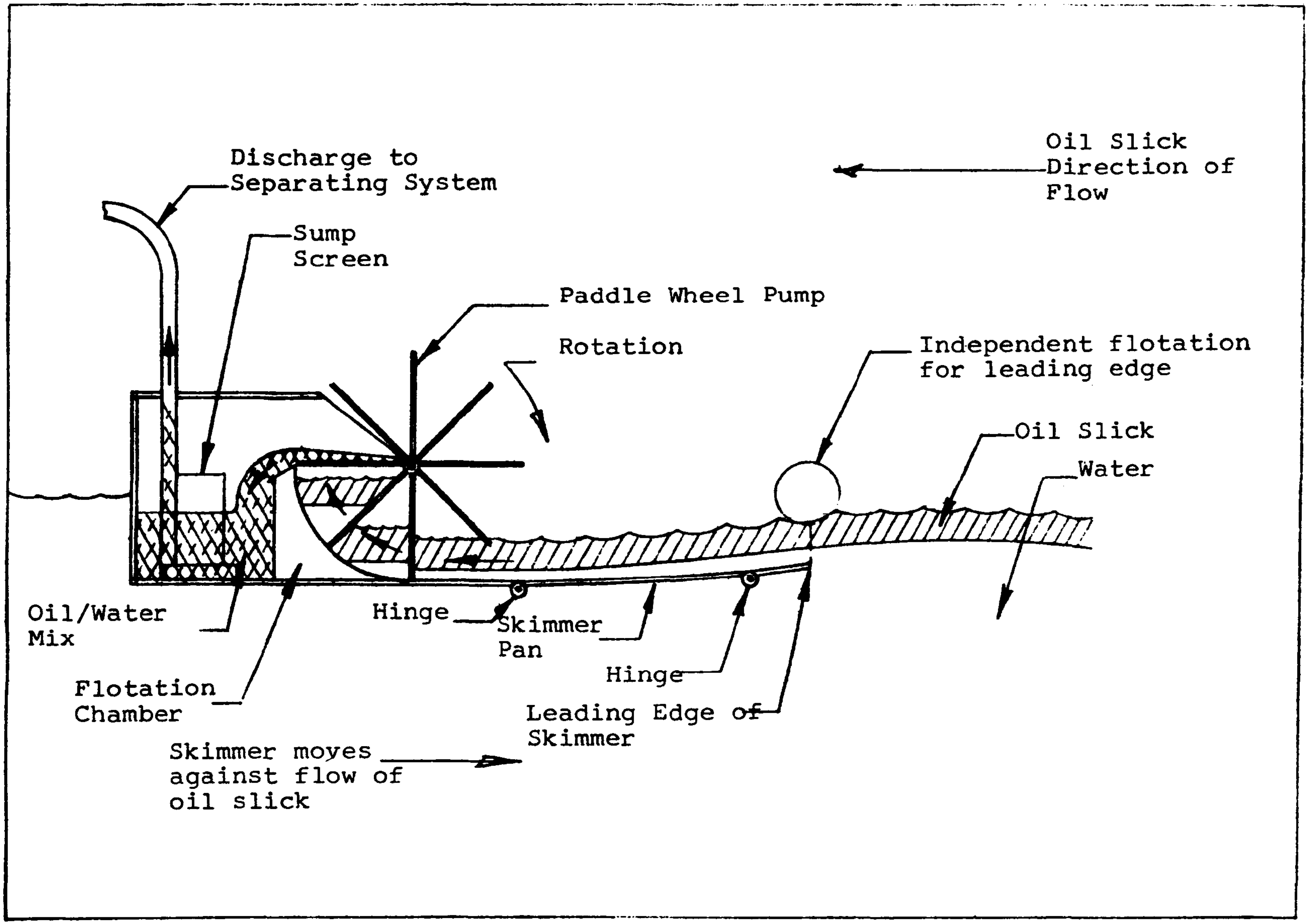
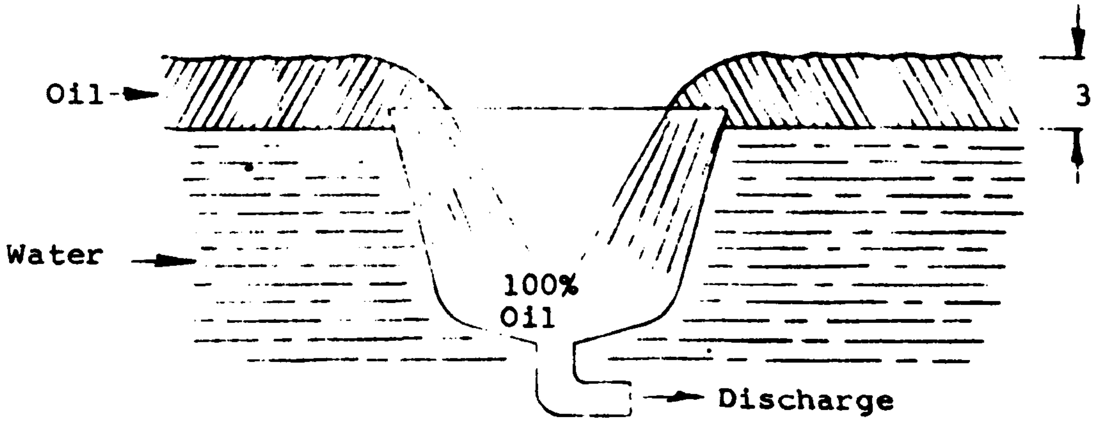
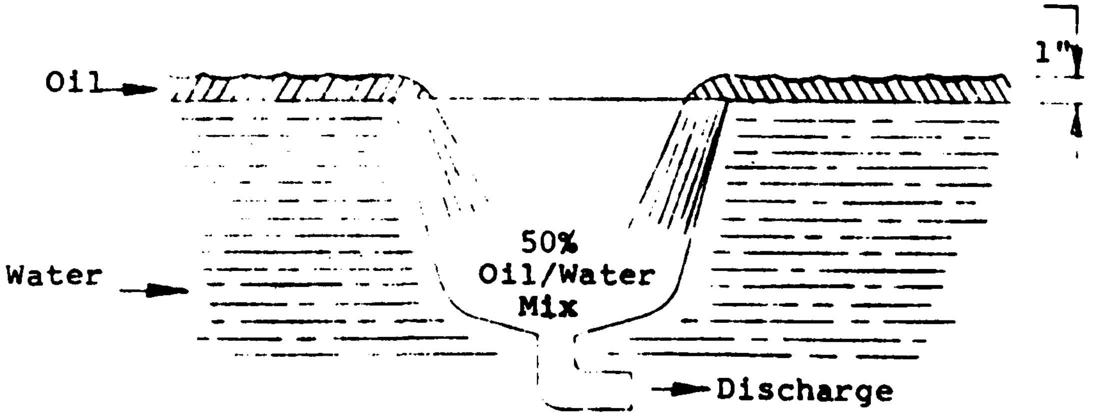


Exhibit 15.

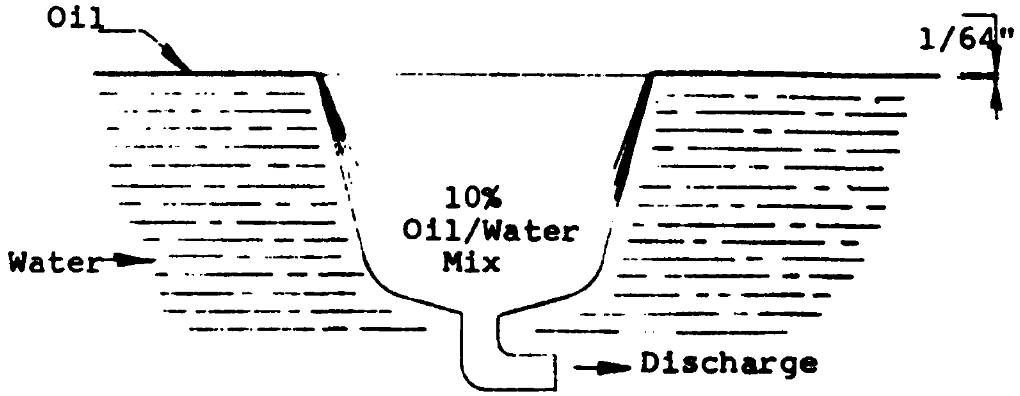
EFFECT OF OIL THICKNESS ON EFFICIENCY OF WEIR SKIMMER



Weir Set 2" Deep in A 3" Slick
Skims 100% Oil



Weir Set Level With Interface
Skims an Oil/Water Mix. Ratio
Depends on Wave Action.



Weir Set as High as Possible Skims
More Water Than Oil, Thus Removes
Oil Very Slowly.

Exhibit 16

ALTERNATE SYSTEMS FOR

RECOVERY, RECLAMATION AND DISPOSAL

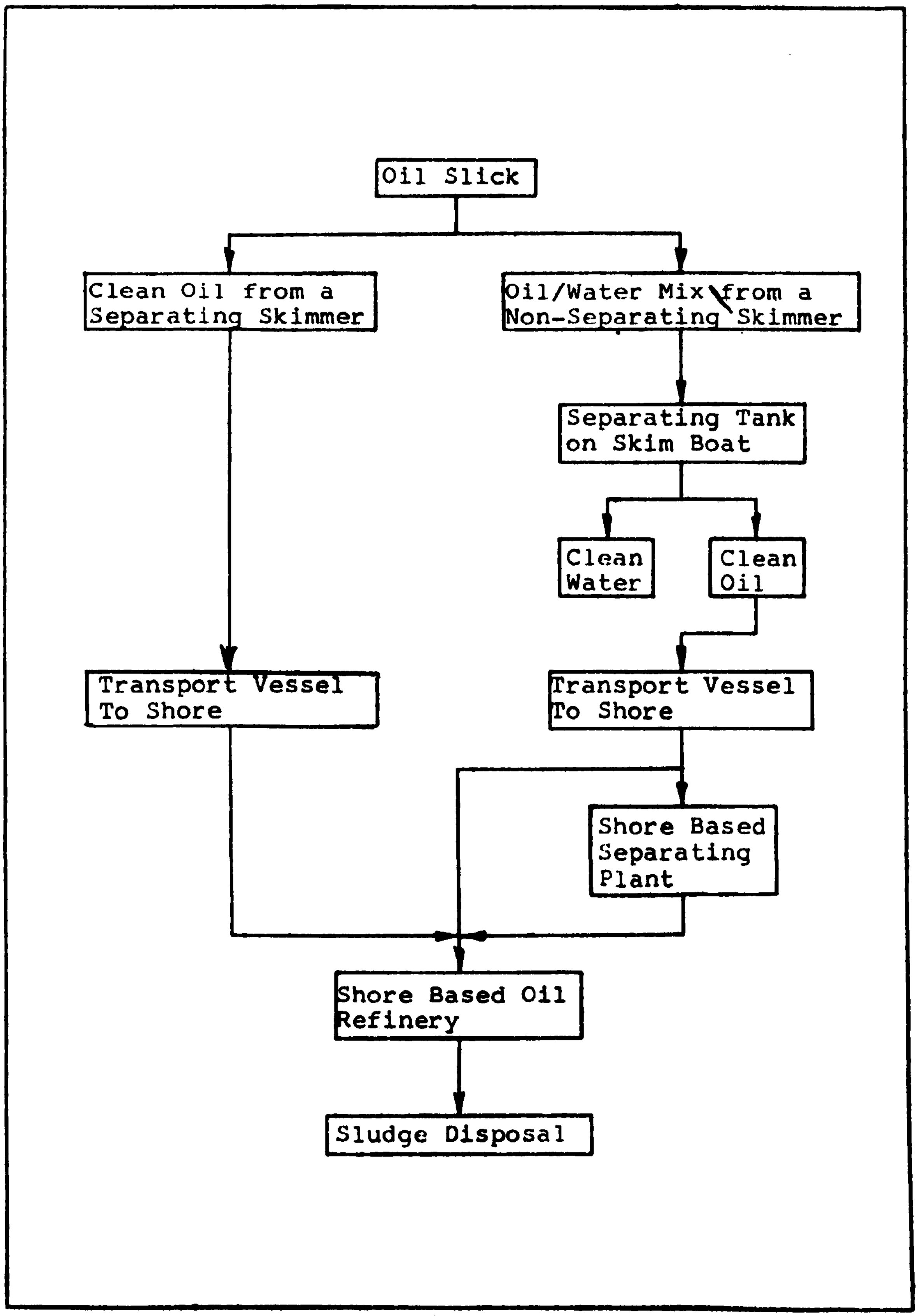


Exhibit 17.

SEPARATING TANKS

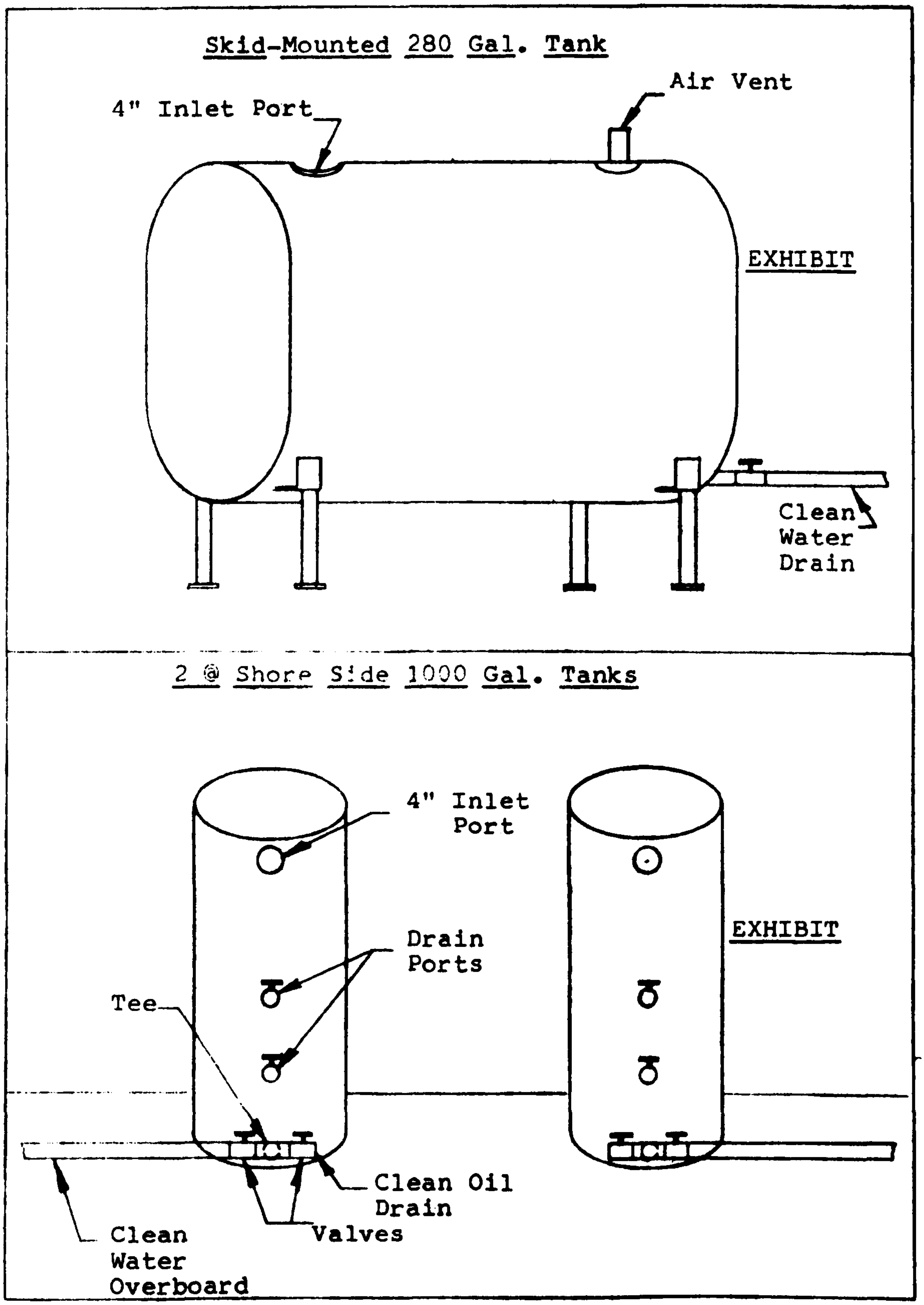
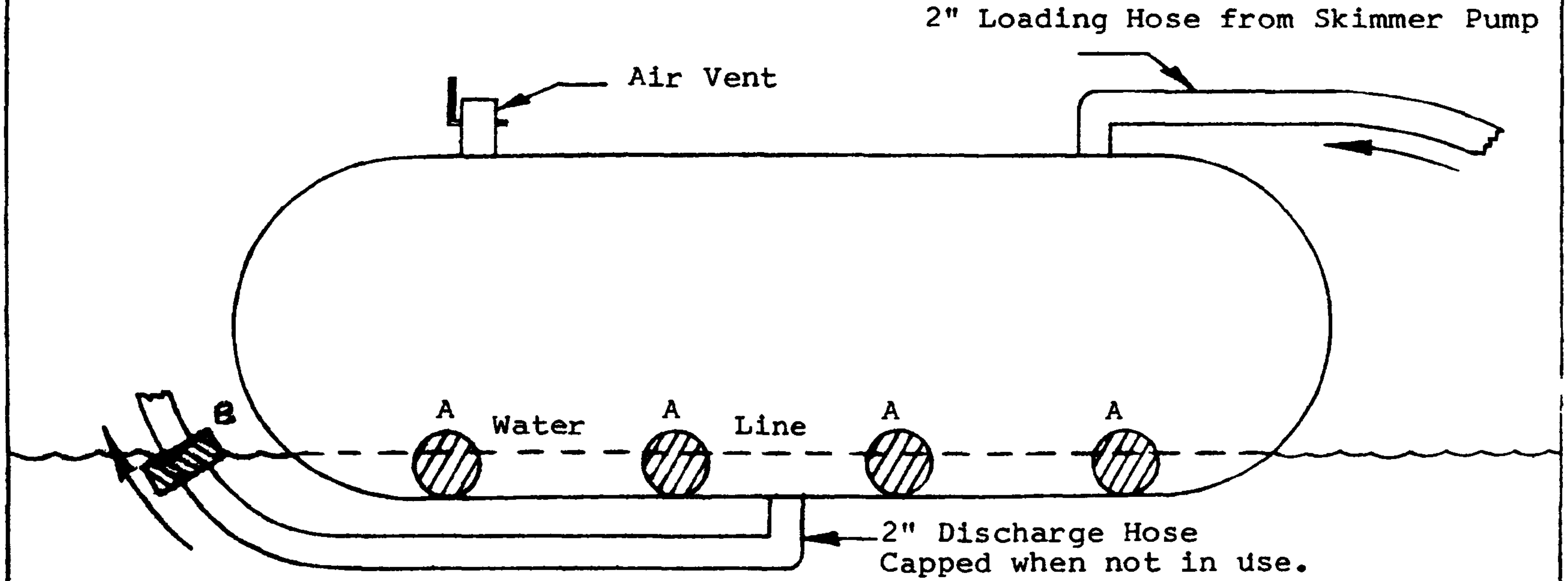


Exhibit 18.

FLOATING TANK



A – Auxiliary Floats
To Support Deflated
Tank and For Visibility.

B – Float to Support End of
Discharge Hose.

Tank Dimension – 60' Long
– 5' Deep – (Inflated)
– 12' Wide

Tank Capacity – 5000 Gallons

OPERATIONS INFORMATION ON FOLLOWING PAGE

Exhibit 19.

LOADING PROCEDURE

Pump oil/water mix into tank through Loading Hose. Open air vent as necessary to relieve internal air pressure during loading. Close air vent and cap loading hose when filling is completed.

TOWING PROCEDURE

Tank tows easily if kept semi-inflated or fully inflated. If fully loaded, tank will be awash and auxiliary floats are recommended so that tank will be visible to other traffic.

PRIMARY SEPARATION OF OIL/WATER CONTENTS

Moor tank in smooth water for 2 hours or more. Oil and water will separate by gravity.

DISCHARGE OF CLEAR WATER

Clear water can be pumped out through Discharge Hose, using any available suction pump. Outlet from suction pump should be monitored so that pumping can be stopped as soon as oil appears in the discharge.

PUMPING OF RESIDUAL OIL

After clear water is pumped out, Discharge Lines can be used to pump residual oil/water into shore-based separating system for final separation and disposal. Air vent can be opened during discharge if needed, but this has not been necessary to date.

Exhibit 20.

AERIAL OBSERVATION PROCEDURE FOR REPORTING OIL SPILLS

Observation of a Suspected Oil Spill	Pilot or crew of Military or Naval Aircraft, Scheduled Air Carrier or General Aviation Aircraft observes a suspected oil spill.
Radio Report to Air Traffic Control Flight Service Station or Control Tower	Pilot reports "I have sighted an oil spill. Can you receive my report on this frequency?"
Detailed report to Communication Station ready to Copy.	Pilot changes to frequency of station equipped to copy, and gives location, size of spill, local weather, surface areas threatened by spill and other pertinent information.
Radio station notifies nearest Coast Guard facility by radio or land line.	Coast Guard acts to notify officials in area threatened, starts air or surface investigation of report and cooperates on execution of any Contingency Plan.

Notification to Civil Agencies

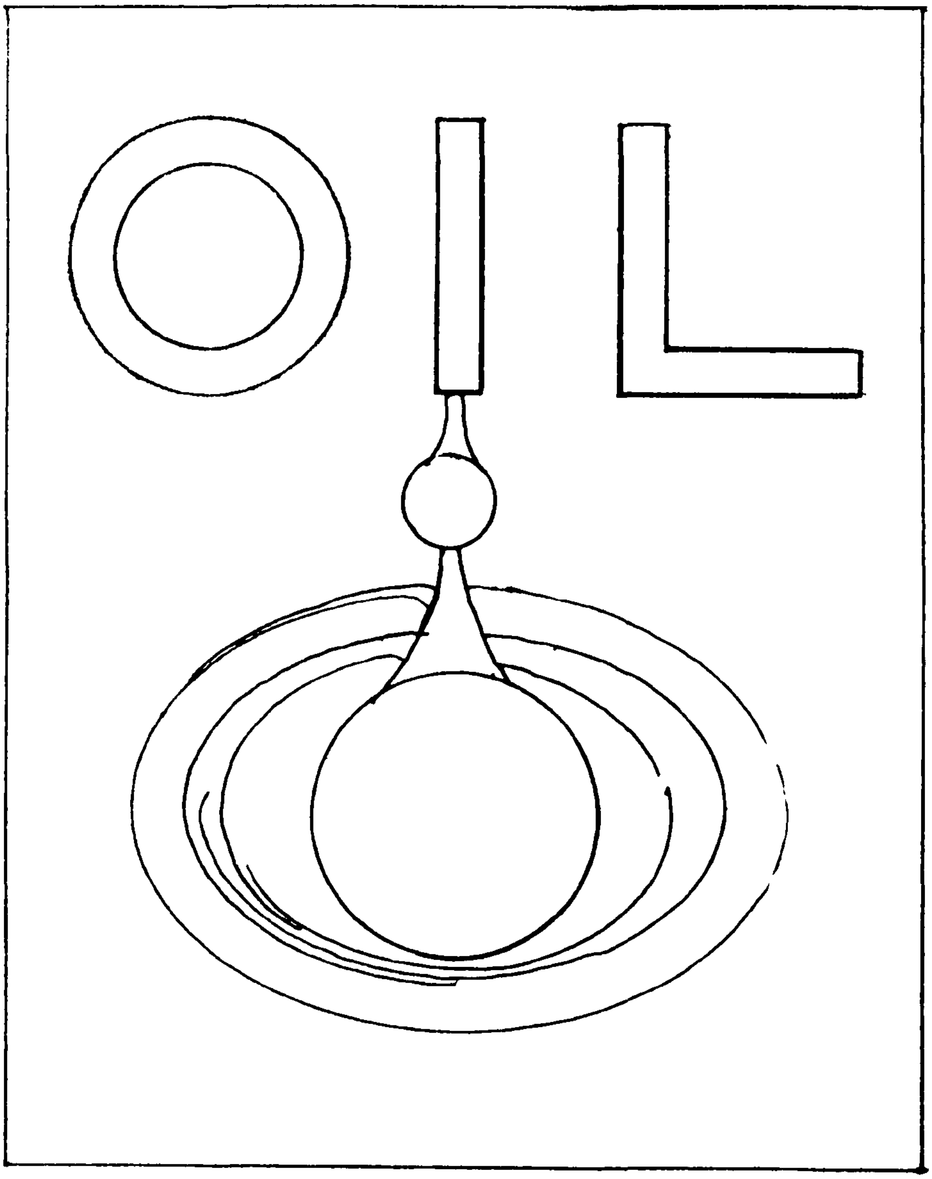
Notification to Government Agencies

Notification to Personnel in threatened areas.

Local Contingency Plans are activated to the degree necessary for the situation.

Exhibit 21.

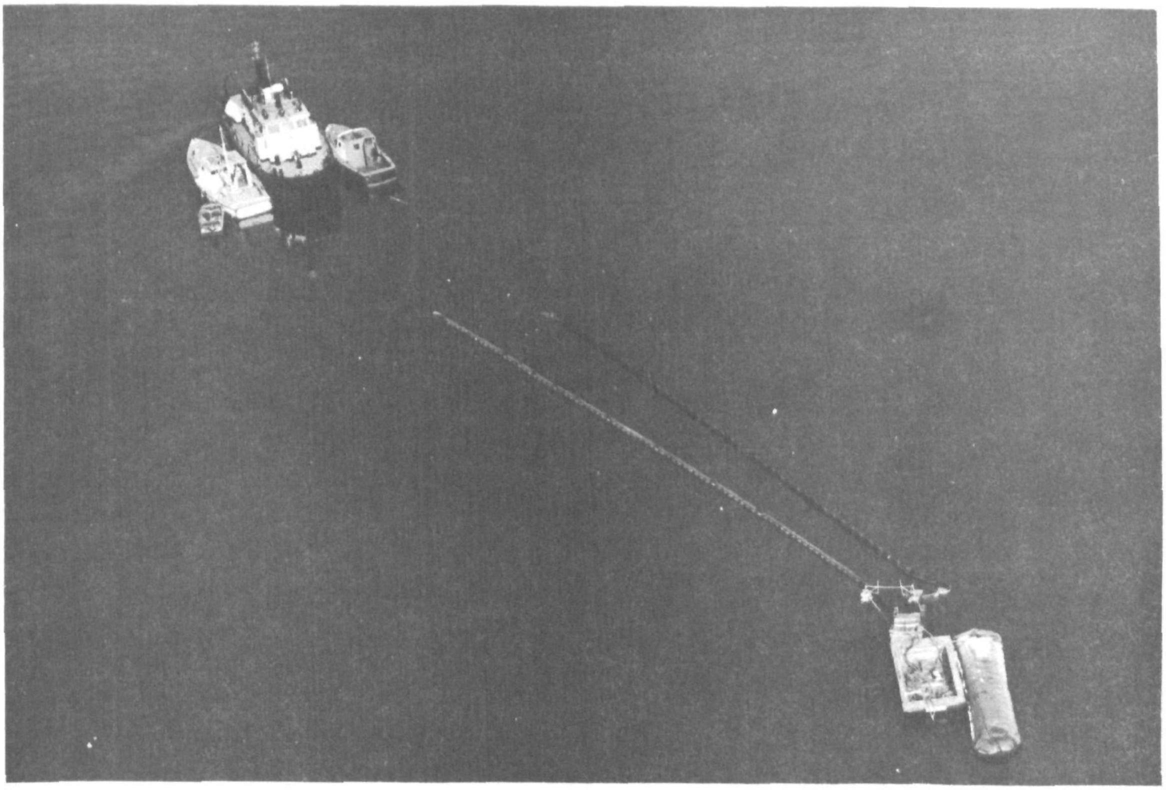
Suggested Design for an
OIL POLLUTION WARNING POSTER



Note: This design could be used as an International Oil Pollution Warning Placard. It could also be mounted on an anchored float at the site of an oil spill. It could be made of a self-destruct material which would disintegrate when desired.

Exhibit 22.

SYSTEM TEST - FUNNEL BOOM



Portland (Maine) Fireboat serving as Command Post and Observation Platform during SYSTEM TEST. Equipment includes Tow Boats, Fence Type Booms used as a funnel, articulated Skimmer (experimental prototype) pump barge and fabric storage tank.

Exhibit 23.

EFFECT OF WIND OR CURRENT ON FUNNEL BOOM

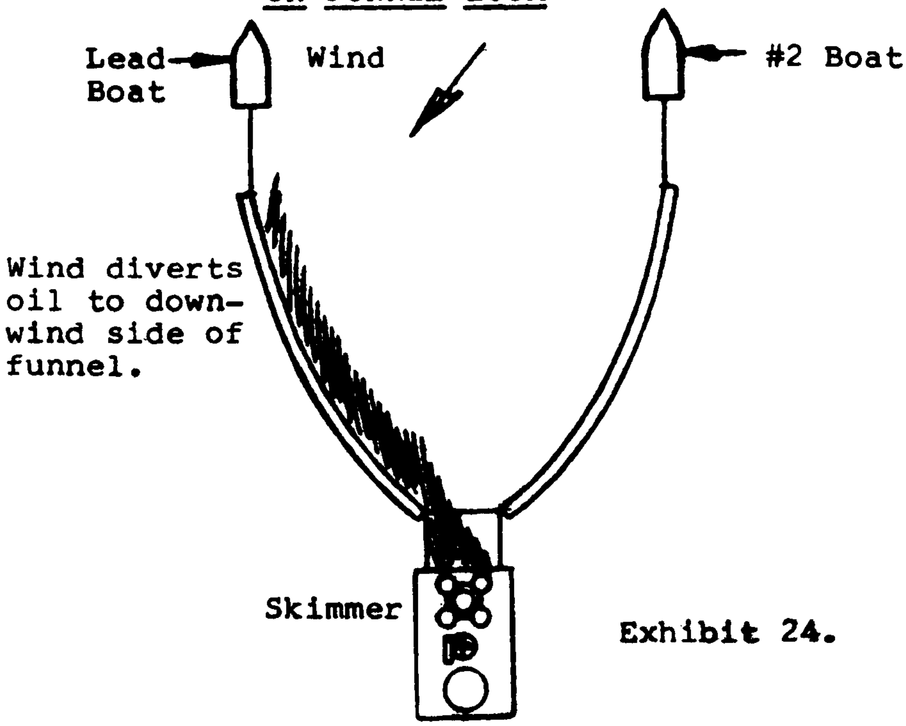


Exhibit 24.

WIND AND CURRENT EFFECT ON SPILL FROM OFF-SHORE OIL WELL

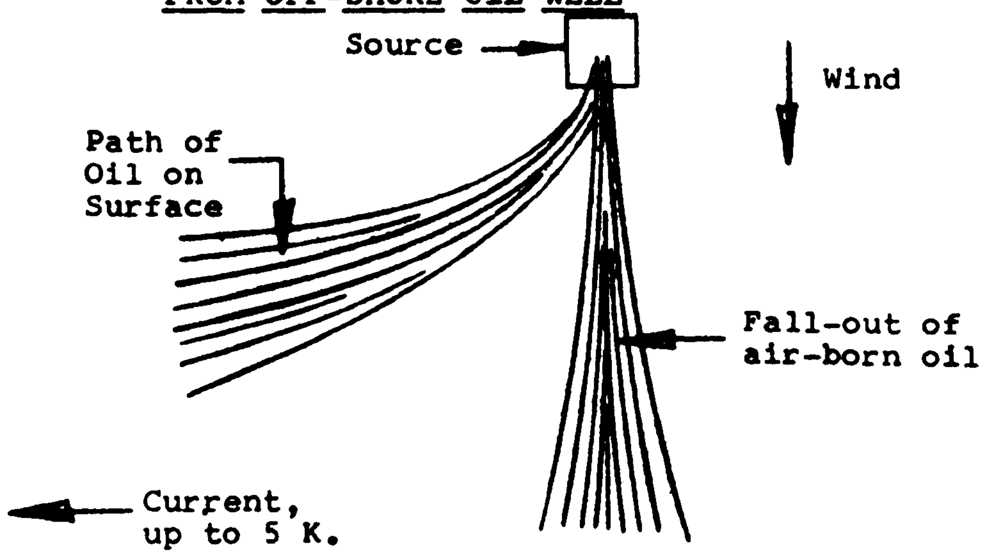


Exhibit 25.

EFFECT OF AIR BARRIER CURRENTS ON A WIND-DRIVEN OIL SPILL

According to literature on the subject, a thin film of oil will tend to move across the surface of the ocean in response to the lower level winds which are prevalent in the area.

It is generally agreed that the oil will tend to move at a speed of 3.8% to 4% of the speed of the wind above it. (Effect of water current being zero.)

Floating objects, however, tend to float at the speed of the current in which they are carried, wind effect being zero.

If we assume an oil slick being driven West by a 30 Knot breeze toward an air barrier which is generating a surface current of 1.25 Knots in an Easterly direction, we find that the speed of the oil slick toward the North is 4% of 30 Knots or 1.2 Knots.

Therefore, we would expect the force generated by the air barrier to stop the Northerly movement of the oil spill at a point about 2' from the Z line of the barrier.

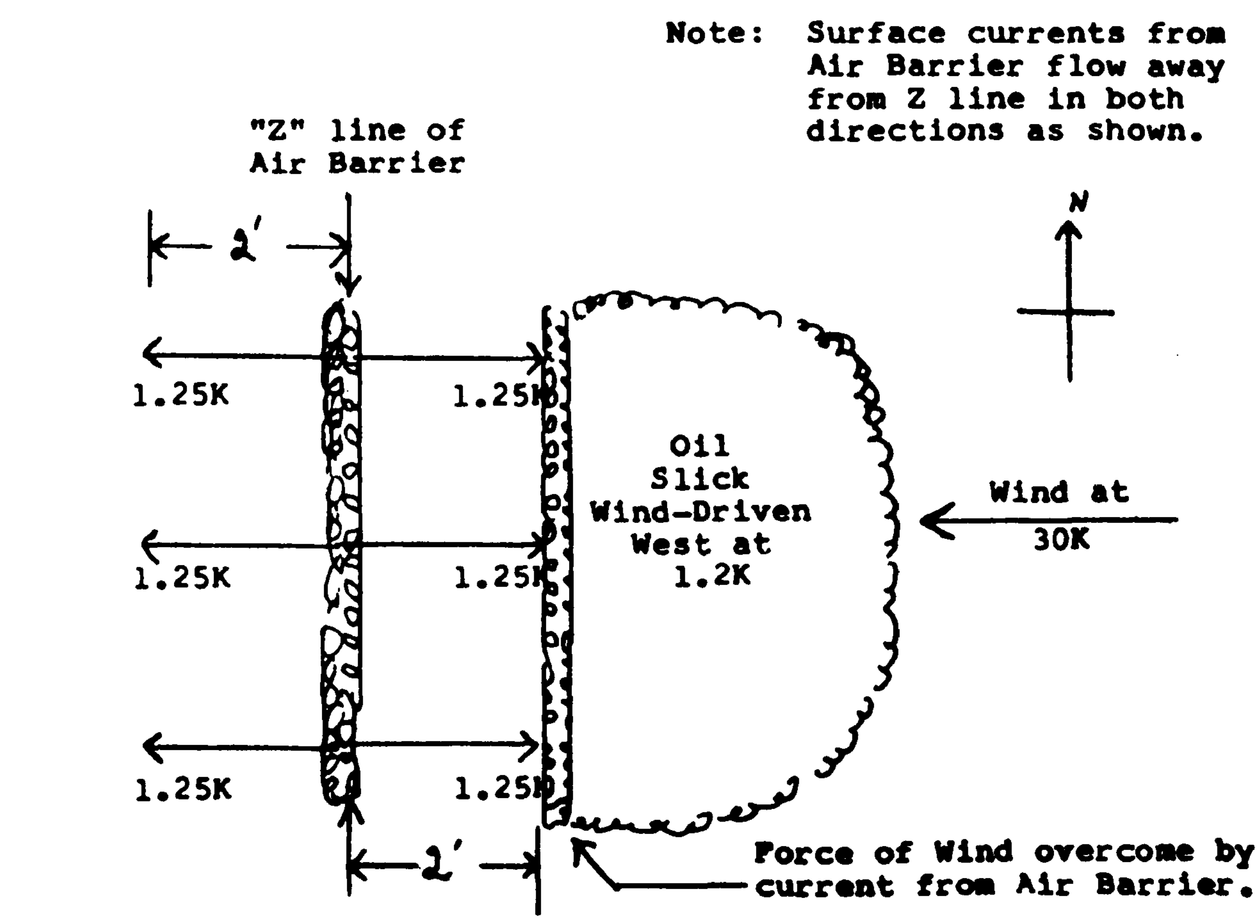
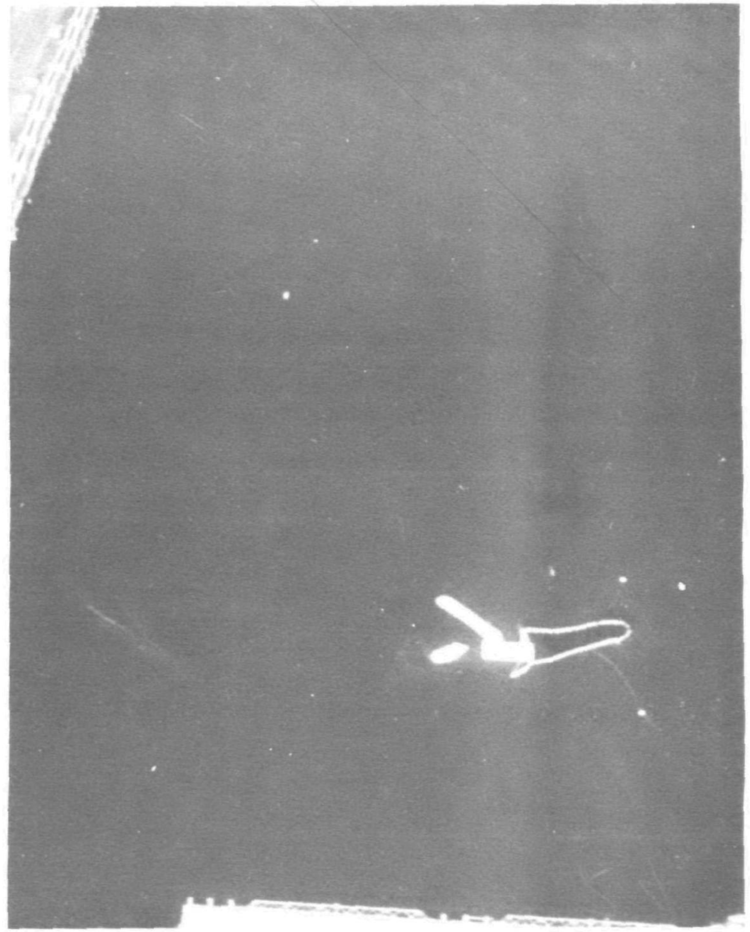


Exhibit 26.

Exhibit 27.

U. S. GOVERNMENT PRINTING OFFICE : 1971 O - 415-664

Tri-X Pan



Infrared

Aerial Photos October 9, 1969 1350 EDT

Pen is positioned 200 ft off the pier head. Oil leaks in two places are more visible with Tri-X pan.

Pollution streak is seen in IR approaching from left of pen. Airplane shadows visible.