Oil Spill Response Technologies

INTRODUCTION

The capability to respond effectively to a major offshore oil spill is a combination of three principal factors:

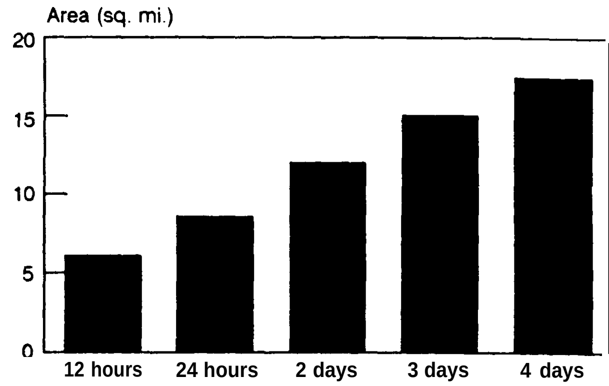
1. the physical conditions at the time of the accident or spill;
2. the suitability, capacity, and availability of the technology deployed to fight the spill; and
3. the skills, training, readiness, and decisionmaking capabilities of the organizations and people with responsibilities for combating the spill.

This OTA study focuses on the second factor while recognizing the major influences of the other two and how they interact.

Adverse physical conditions that may be present at any spill site always contribute to the difficulty of responding efficiently and effectively. Some of the key conditions that affect a response effort include:

Spreading of Oil. Oil spilled on the water spreads rapidly. The spreading rate depends on the type of oil, its volume, wind and sea conditions, and the amount of weathering that occurs. Figure 3-1 shows the effect of spreading for calm water conditions and uniform slick thickness–not necessarily real world conditions. It can be seen that, for an *Exxon Valdez* type of spill, the oil can spread over 6 square miles (almost 4,000 acres) during the first 12 hours.[1] The huge area encompassed by a large spill means substantial amounts of equipment are needed to respond. Spreading also enhances evaporation and solution of the oil by creating a large active surface area. In addition, an oil slick tends to fragment into a number of smaller patches with time, and thus, even larger total surface areas must be covered with any available recovery equipment.

Figure 3-1 -Spread of an Exxon Valdez-Sized Oil Spill



Note: Assuming no wind or current

SOURCE: Engineering Computer Optecnomics, Inc (ECO)

Composition of Oil. The viscosity of the oil can be a critical factor in the response effort. In addition, oil spills in rough seas quickly become emulsions as they mix with water and form "chocolate mousse, " a substance which is very difficult to pump. High viscosity oils are more difficult to recover mechanically and disperse than low viscosity oils. Also, weathering processes such as evaporation, water take-up, oxidation, and biodegradation will increase the viscosity. Certain crude oils (such as Alaskan crude) become very difficult to pump when temperatures reach about O to 5 degrees Celsius. In addition, the effectiveness of dispersants and the burning process decreases as viscosity and emulsification increase. Also, the total volume of oil/water emulsion (mousse) can reach several times the initial oil spill volume.

[1] If all of the containment boom in the U.S. Navy inventory could be deployed to this type of spill site within the first 12 hours, it would barely be enough to encircle such a spill. In fact, the U.S. Navy response was not even requested until more than 1 week after the *Exxon Valdez* accident.

Sea Conditions. Most existing mechanical equipment becomes much less effective in waves greater than 3 to 6 feet. In addition, small vessels cannot be used, and deployment of gear in rough seas can be difficult. Currents can cause oil to move in unpredictable directions, and booms become ineffective when current velocity exceeds about 1 knot perpendicular to the face of the boom.

Weather Conditions. Weather such as snow, fog, heavy rain, high winds, and low temperatures all adversely affect the deployment and operation of equipment.

Location of Spill. If the spill is near the shoreline and the drift is toward shore, it will be very difficult to prevent beach contamination, no matter how ideal the conditions. The more remote a spill, the more difficult it is to get equipment to the site quickly.

Logistics. It is critical to be able to move equipment and personnel to the spill site as rapidly as possible. Also, all aspects of the transportation network are important–barges and other support vessels are often overlooked or not available.

Safety. Response to a large spill must include consideration of fire and explosion potential of the slick under the right temperature and atmospheric conditions. The protection of people aboard the vessel and those working on clean-up operations is critical. The safety of the stranded vessel itself is also important, especially if part of the cargo can be recovered before it is all spilled.

The above factors affect the ability of any response effort to mitigate the effects of a large offshore spill. OTA has reviewed three major categories of existing technologies for oil spill response: mechanical recovery; dispersants; and burning, bioremediation, and other techniques. In general, none of the currently available technologies are adequate to respond to and mitigate major offshore spills of the *Exxon Valdez* type and size (over 10 million gallons).

In the United States, almost all of the existing technology in the private sector has been developed for use in harbors and other protected waters. The Coast Guard and the Navy have equipment in their inventory that was designed for offshore areas in terms of deployability and ruggedness, but it is limited to moderate sea states, low currents, and moderate-size spills. No private U.S. oil spill cooperative has the ability to deal with large, catastrophic spills. The few large cooperatives in the United States have equipment that is more appropriate for platform spills. The Coast Guard has only minimal equipment of its own and depends, in large part, on private industry to supply systems to respond to spills. The Coast Guard has not developed any new equipment in recent years, and the number of strike teams has been reduced from three to two. The Navy's spill response capability is probably more substantial than that of any other government agency, but its equipment has been designed to be air-transportable and, thus, is limited in size and capacity.

MECHANICAL SPILL RESPONSE TECHNOLOGIES

Mechanical recovery of spilled oilcan be accomplished by a variety of techniques. A large number of different systems have been designed and built over the last 20 years. The *World Catalog of Oil Spill Response Products,* for instance, includes hundreds of harbor, calm water, and offshore booms and skimmers designed for a variety of spills and conditions, in addition to hundreds of sorbants that soak up oil.[2] Oil spill containment and

[2] Robert Schulze (d.), *World Catalog of Oil Spill Response Products* (Baltimore, MD: Port City Press, 1987), 470 pp.

cleanup technology has improved marginally over the past two decades, but private and Federal research efforts in the United States diminished greatly in the 1980s. Mechanical spill response technologies can be divided into two major categories: containment booms and oil recovery devices. Several containment and cleanup devices are discussed below. More details are included in appendix A.

Booms

Booms range in vertical dimension from under 1 foot for protecting calm water areas to over 7 feet for offshore applications. Smaller booms are less expensive, lighter, and easier to deploy. Large offshore booms require larger boats, heavier equipment, and often specialized equipment to deploy and recover. Most booms, including large offshore booms as well as smaller booms, become ineffective in currents over 1 knot and wave heights over 6 feet. Systems designed for more severe conditions in the Norwegian sector of the North Sea are required by the Norwegian government to be effective in waves up to 9 feet and currents of 1.5 knots. However, in wave heights in the range of 6 to 9 feet, the efficiency of the equipment decreases as oil escapes the boom. In wave heights above 9 feet, oil is whipped into the water and splashed over the booms, and little recovery is possible.

One type of boom, designed for rapid deployment, is pumped full of air (in an upper flotation chamber) and water (in a lower ballast chamber) as it is pulled off a reel. Thus, one trade-off is between rapid deployment using continuous air inflation versus slower deployment but less reliance on continuously operating inflation equipment. Booms that can be deployed from a reel and do not require

Photo credit: Vikoma International, Lti.

A weir boom corralling an oil spill.

that sections be bolted together are generally easier to handle offshore. Future developments are not likely to be in the direction of greater ability to operate in harsher sea conditions but more toward ease of operation within the limits now attained.

Booms ranging from 18 inches to 80 inches were used at the Exxon *Valdez* spill in Prince William Sounds According to one spill response supervisor at the spill, the largest booms were no better at containing oil than booms in the 32 to 42 inch range, but the larger booms were useful to slow down the larger boats that could not otherwise tow slowly enough.[4]

[3]Engineering Computer Optecnomics, Inc. (EC! O), "Analysis of Oil Spill Response Technologies, " contractor report prepared for the Office of Technology Assessment, July 1989.

[4]Ibid.

Photo credit: Jim Mielke

Heavy-duty boom on reel at the Southampton, U.K. Oil Spill Service Centre.

Air bubble barriers are another type of containment device. If air is pumped into a perforated pipe below the water surface, the rising bubbles cause the surface water to flow away from the pipe. Air barriers are more effective in calm waters and when used at freed installations. An air bubble barrier was employed in the 1969 Santa Barbara spill with little success. This equipment requires large amounts of compressed air and presents logistical problems, which probably would make it unsuitable for remote areas.

A promising future addition to containment technology may be the high pressure water jet barrier. The water jet system is designed to herd oil, much like a barrier, but under a wide variety of operating conditions. It can be mounted on and used with oil recovery devices.

Skimmers

Several basic types of skimmers are available; some of the more common are suction and weir skimmers and skimmers with a moving surface such as a belt, oil-absorbent rope mop, or disks (see appendix A). Each has its strengths and weaknesses, and no single type is best for all situations or types of oil. Even the most effective skimmers have rarely accounted for recovery of more than a few percent of oil from large spills.

Suction skimmers generally have a fairly high oil recovery rate because of their high pumping capacity, but they do not discriminate well between oil and water and thus have a low recovery efficiency.[5] They are simple to operate but do not work well in choppy waves. **Weir skimmers** have the advantages of being simple and reliable, and they have a fairly high recovery rate. However, most (especially rigid types) do not work well in waves. Conventional weir skimmers also have problems in becoming clogged with debris. There are a variety of belt **skimmers,** some with belts of absorbent material, some without, and some that can be used either way. Belt skimmers with the belt inclined to the water and the upper surface moving upward can generally handle debris very well. They also can be expected to have a relatively high oil recovery rate and high efficiency. **Disk skimmers** rely on the adhesion of oil on rotating disks. Because of the large vertical dimensions of the disks, they are relatively more effective in waves, and the larger skimmers are effective in fairly high sea states. Disk skimmers have a high recovery efficiency, which can be a considerable advantage if storage volume is limited. Among their disadvantages are their vulnerability to becoming clogged with debris, their ineffectiveness with mousse, and their more complicated design (which makes them more likely to break down). Rope **mop skimmers** have a long loop of absorbent oleophilic (oil loving) material that floats on the surface of the water

[5]The oil recovery rate, measured in gallons per minute, is the rate at which pure oil is recovered. Recovery efficiency is the percent oil in the recovered mixture. Robert Schulze (cd.), *World Catalog of Oil Spill Response Products* (Baltimore, MD: Port City Press, 1987), p. 213.

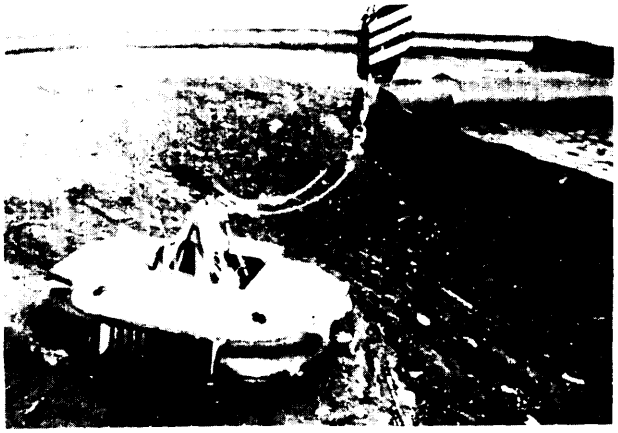


Photo credit: Vikoma International, Ltd.

A disk skimmer deployed behind a boom. This model has the capacity to recover about 50 tons of oil per hour.

and is then pulled through a wringer to remove oil. These skimmers have a high recovery efficiency, are easy to deploy off the side of a vessel, and are relatively easy to maintain.

Evaluation of Capabilities

In wind and currents, a boom must be designed with proper ballast to remain vertical and to maintain an effective height in the water. Other problems of containing oil in a current are related to the hydrodynamics of oil in moving water. As an oil slick increases in thickness against the boom, the oil extends deeper into the water. Only about 10 percent rises above the waterline. In other words, an oil slick floats in much the same way as an iceberg. As current velocity increases, more oil is driven against the barrier. When a critical velocity for the depth of the barrier is exceeded, oil will migrate down the barrier and escape underneath. Another problem is entrainment or dispersion of oil droplets in the water as it flows past oil held against a barrier. The rate at which droplets of oil enter the water and flow beneath the barrier depends on the current speed (or the relative velocity between the barrier and the water if the barrier is being towed) and properties of the oil itself. Both entrainment and migration of the slick under a barrier become significant problems at current speeds in excess of 1 knot perpendicular to the boom face.[6] Badly designed booms may fail below this current speed. The difficulties in handling barriers in open ocean waters are compounded by the fact that ships towing booms must navigate at very slow speeds where it is difficult to maintain steering control.

Booms have probably reached their practical limits in terms of the maximum wind and wave conditions in which they can be expected to retain oil. Additional improvement will most likely result from advances in ease of deployment and possible development of new, lighter weight, durable materials.

Skimmer performance varies widely depending on the viscosity of the oil being recovered. Most skimmers have a range of viscosities in which they work best and can be roughly grouped according to the oil viscosity in which they are most effective. A generalized grouping of skimmer performance according to oil viscosity is shown below.

Light Oil
Weir
Suction
Submersion belts
Submersion plane

Medium Oil
Disk
Rope mop
Sorbent belt
Sorbent lifting belt
Sorbent submersion belt
Boom-skimmer
Vortex

(continued)

[6] 1 knot equals 1.2 miles per hour.

Photo credit: Jim Mielke

A "Foxtail" rope mop skimmer deployed in a Norwegian test tank.

Heavy Oil
- Paddle belt
- Sorbent lifting belt disc (large offshore types only)
- Rope mop (high viscosity, but not Bunker-C)
- Weir with progressive cavity pump

In general, even the most rugged mechanical containment "and recovery equipment is limited in effectiveness to waves of less than 6 feet, winds of less than 20 knots, and currents less than 1 knot. Average wind and current conditions in many U.S. port areas come close to these limits leaving little margin for effective use of mechanical equipment. Thus, it would be normal to expect periods when weather conditions would preclude operation of mechanical containment and recovery equipment in any U.S. port area.

Even under ideal conditions, with equipment and trained personnel nearby and good weather, it is not realistic to expect to recover more than 30 percent of the oil from a major spill. Probably less than half that amount is more likely. The rapid spreading and fragmentation of oil that occurs after a spill has made cleanup of large percentages of oil exceedingly difficult. Historically, recovery from major spills has amounted to only a few percent, if there was any attempt at recovery at all.

Mechanical Cleanup Enhancers

A number of products have been marketed to assist in the recovery of spilled oil. One chemical that has undergone preliminary testing and appears to offer some promise is a nontoxic polymer, polyisobutylene, which comes in the form of a white powder and renders oil visco-elastic. This change makes the oil adhere to recovery surfaces, thereby greatly increasing the effectiveness of oil skimmers, particularly rotating disk and drum types. Rope mop type skimmers do not appear to be well suited to the use of this treating agent because the increased visco-elasticity makes the squeezing of the rope more difficult. This material has also been shown to be effective at treatment ratios as low as one part in 1,000.[7] It does not appear to reduce spreading or increase thickness sufficiently to assist in situ burning. One potential problem may be applying and mixing it with oil in large, spread-out spills.

Other chemicals have been developed to break or prevent emulsions. These products have the ability to convert the water-in-oil emulsion to two separate phases. The advantage of doing this is that the oil can then be

[7] Merv F. Fingas, "Chemical Treatment of Oil Spills," Alaska Arctic Offshore Oil Spill Response Technology Workshop Proceedings, U.S. Department of Commerce, National Institute of Standards and Technology, NIST Special Publication 762, April 1989, p. 33.

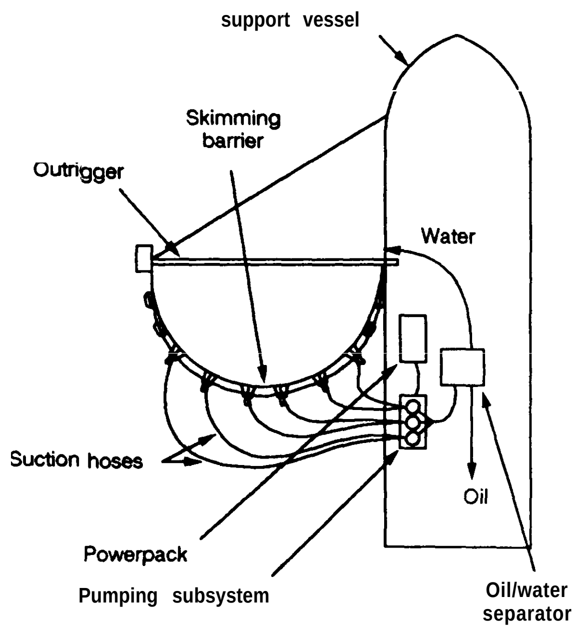
recovered more efficiently or dispersed or burned more successfully. Most of these products are hydrophilic (water-loving) surfactants. The problem with these surfactants is that the surfactant is more soluble in water than in oil and will quickly leave the system if there is sufficient water. One product being tested by Environment Canada is a demoussifier – a mixture of long-chain polymers that does not have the drawback mentioned above. Although not yet available, laboratory tests show this material will prevent the formation of water-in-oil emulsions at treatment ratios as low as 1:2,000. As with other treating agents, application and mixing in large spills may be difficult. Like dispersants, mechanical cleanup enhancers require certification before they can be considered for use.

Integrated Systems and Deployment

The difficulties encountered in spill responses with respect to obtaining and deploying boom and skimmer handling vessels and oil storage vessels have led to the propositioning of chemicals and equipment and development of integrated systems that are equipped to perform all the functions of the mechanical recovery process. Integrated systems fall into three categories: vessel-of-opportunity systems; single purpose, specially designed oil spill response vessels; and multiple purpose vessels, of which one of the purposes is oil spill recovery. These systems use conventional skimmer techniques to recover the oil and are subject to the efficiencies and shortcomings of those systems. However, they also have the advantage of being independent of other supporting equipment in their recovery process, until their storage capacity is exceeded.

Vessel-of-opportunity skimming systems (VOSS) are systems designed to be deployed *from* **any** suitable vessel that maybe available in the area. They incorporate portable skimmers that are not integrated into a dedicated vessel. The skimmer system is freed to the side of the vessel, and recovers oil while the

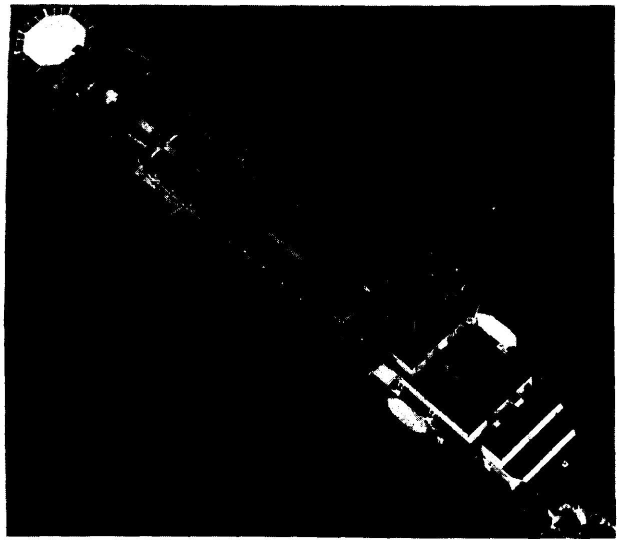
Figure 3-2-Vessel-of-Opportunity Skimming System



SOURCE: Engineering Computer Optecnomics, Inc (ECO)

vessel progresses through the slick (figure 3-2). While these systems have the advantage of greater mobility, they are limited to the suitability of vessels in the area.

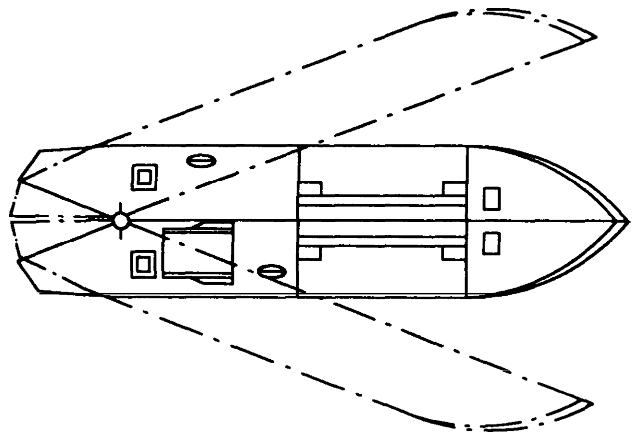
Specially designed oil spill response vessels capable of operating in the open ocean have been developed by European firms, mainly Dutch and German. These are large vessels, unlike some of the smaller skimmers described previously. One of the more innovative is a tank vessel hinged at the stern that operates in a “V” configuration, using its split hulls to form a boom-like collecting system (figure 3-3). Two of these vessels are in use and a third has been ordered by Mexico. These systems have the advantage of being complete systems with significant onboard oil/water separation capability and storage capacity. Disadvantages include their high cost and, since they are not air transportable, their more limited range of use.



Pho credit: IHC Ho nd

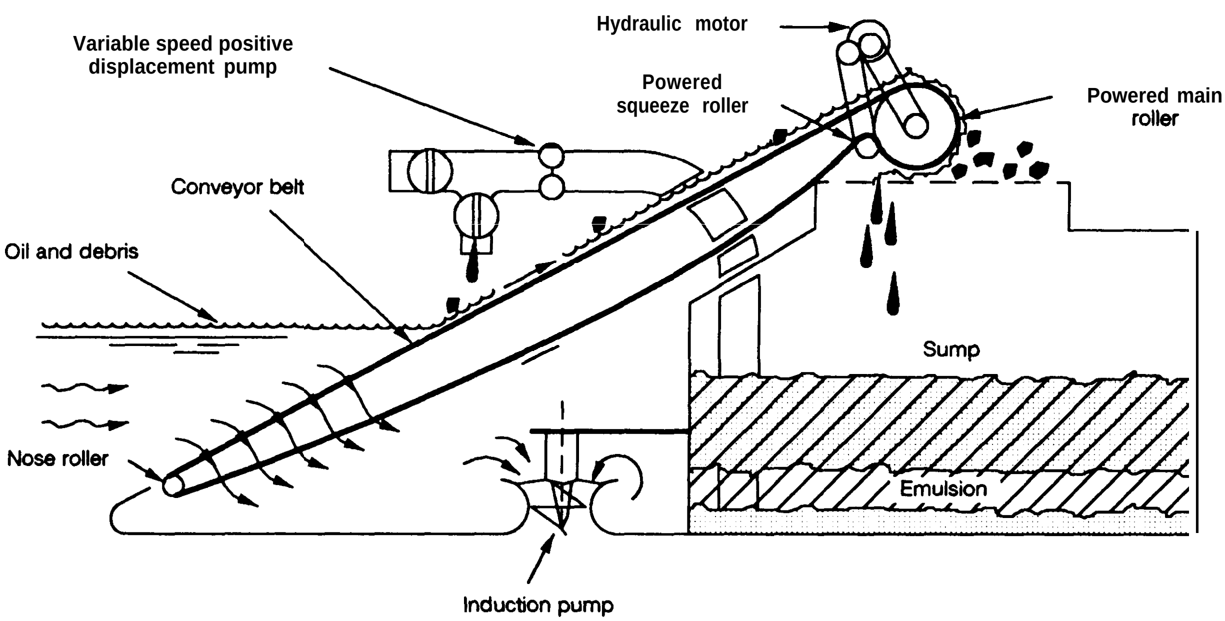
The *Co mo* d p rpose sse b lt both dredg g nd recoveri g The mm ng rm d p ed th p to

Figure 3-3-Schematic Drawing of West German Split Vessel *THOR*



SOURCE: IHC Dredge Technology Corp

Figure 34-Schematic Drawing of the Navy's Class V Oil Skimmer



SOURCE: U S Navy

Multiple-purpose vessels are an economical approach to large-scale, oil spill response systems. The publicity surrounding the use of the Soviet dredge in the Exxon *Valdez* spill has focused attention on the use of dredges and other vessels as platforms for oil spill response systems. The Soviet dredge was designed from the beginning as a trailing hopper dredge with oil recovery capability. The first report of building a dredge with the dual role of oil spill response was in 1977 with the design of the Cosmos, a Dutch ship. The great capacity of these vessels for storage of viscous materials and their pumping systems (including suction hoses up to 24 inches in diameter) make them ideal for recovering very viscous weathered oil. U.S. Army Corps of Engineers dredges were also used in the Alaskan oil spill, but without specific modification. Initial design modifications would include spark suppressing electrical systems, oil/water separation equipment, and ventilation systems for dealing with flammable volatiles. Unmodified dredges would be limited to recovering weathered oil that presents no fire hazard. The advantages of dual-purpose dredge vessels are their usefulness as a dredge during most of their lifetimes and their large capacity in the event of a major spill. Both the U.S. Coast Guard and the Army Corps of Engineers are studying the use of multi-purpose vessels. The Coast Guard is studying the feasibility of giving buoy tender vessels oil spill cleanup capabilities, and may add this capability to new buoy tenders as they are built.

Recovery and containment systems cannot be deployed at the site without the provision of significant support resources. These support resources include material handling equipment such as forklifts and cranes, boom and skimmer handling vessels, storage vessels, surveillance airplanes, and trained personnel. Table 3-1 shows the minimum equipment required to *deploy* various response components.

DISPERSANTS

Perhaps the most controversial issue in the field of oil spill response is the use of chemicals to disperse the oil. In general a dispersant is sprayed onto a slick to reduce the cohesiveness of the slick so that the oil can be broken into small droplets by wind, wave, and current action. The oil droplets disperse into the water column where they become diluted to low concentrations and are subjected to natural processes such as biodegradation.

Much of the controversy that has surrounded the use of dispersants has arisen from their impact on the environment. While early dispersants were toxic, modern dispersants are less toxic than the oil itself.[8] Even so, the use of dispersants involves making an environmental trade-off. In essence, this involves trading the potential short-term environmental effects of a treated slick against the possible long-term shoreline impacts and other effects of an untreated one. The primary impact of a dispersed slick comes from the oil dispersing into the upper water column. While it will rapidly become diluted, the initial concentrations may exceed the acute toxicity threshold of organisms in the upper few meters of the water column. In certain seasons or sensitive areas, this maybe a trade-off that authorities are unwilling to make.

In an untreated spill, evaporation may be responsible for the loss of one-third or more of the oil in a period of a few hours or a day. While hydrocarbons dissolved in water also evaporate, many of the hydrocarbons that dissolve (mainly aromatics) appear to produce the most immediate biological toxicity.[9]

[8] National Research Council, Marine *Boat-d, Using Oil Spill Dispersants on the Sea* (Washington, DC: National Academy Press, 1989).

‘Ibid., p. 240.

Table 3-1--Equipment Required To Deploy Response Elements

System	Staging area	To site	Onsite	Personnel (per system)
CONTAINMENT	Space Forklift-4 ton Crane-4 ton Maintenance facilities Spares	Vessel with minimum of 8' x 20' clear deck space for each 2000' of boom	A-frame/davit/handling equipment with minimum one ton capacity Boats capable of tending boom – one if boom anchor used – two if no boom anchor used	2 2 per boat
RECOVERY				
Skimming barrier	space Forklift- l O ton Crane-10 ton Maintenance facilities Spares	Vessel with minimum of 8' x 35' clear deck space per system	A-frame/davit/handling equipment with minimum one ton capacity Two boats for maintaining barrier opening and shape and capable of operating at low speed-1 to 2 knots Barge for receipt of recovered oil Tug to tend barge or to shuttle barge to onshore storage location Platform for prime power (may be barge)	4 to 6
Self-propelled skimmer	Sp ce Forklift-10 ton Crane-10 ton Maintenance facilities Spares	Vessel with minimum of 12' x 35' clear deck space per system	A-frame/davit/handling equipment with minimum one ton capacity Two boats for maintaining barrier opening and shape Barge for receipt of recovered oil Tug to tend barge or to shuttle barge to onshore storage location Boat with 10-ton crane at 35' reach deploy and recover	7 to 8
Vessel-of-opportunity skimmer	Space Forklift-10 ton Crane-10 ton Maintenance facilities Spares	Vessel with minimum of 8' x 24' clear deck space per system	A-frame/davit handling equipment minimum one ton capability for deployment and recovery Barge for receipt of recovered oil Tug to tend barge or to shuttle barge to onshore storage location	3 to deploy 2 to operate
DISPERSANT APPLICATION				
Air deliverable	Pumps to transfer from barrels to tank truck Tank truck Ground personnel	See onsite requirements	Surveillance aircraft for spotting Aircraft equipped to spray dispersant	2
vessel deliverable	Space Forklift-8 ton Crane-8 ton Maintenance facilities Spares	Vessel with 8' x 24' clear deck space	Surveillance aircraft for spotting Vessel capable of accepting vessel system	2 to 3 to deploy 2 to operate
TRANSFER PUMPS	Space Forklift-2 ton Maintenance facilities Spares	Vessel with approximate 8' x 24' clear deck space Helicopter with l-ton lift capacity	Barge for receipt of off-loaded oil Tug to tend barge or to shuttle barge to onshore storage location Hoses and couplings Fenders	

SOURCE: Engineering Computer Optecnomics, Inc (ECO), "Analysis of Oil Spill Response Technologies," contractor report prepared for the Office of Technology Assessment, July 19SS

The immediate ecological impacts of dispersed oil vary. In open waters, organisms on the surface will be less affected by dispersed oil than by an oil slick, but organisms in the water column will receive greater exposure from dispersed oil. In shallow areas, less water is available to dilute the dispersed oil to less than lethal concentrations, so organisms will be more severely impacted by dispersed oil. Consequently, dispersant use is generally limited to deeper water. Although some immediate biological effects of dispersed oil may be greater than for untreated oil, long-term effects on most habitats, such as salt marshes, sea grasses, and mangroves, are less, and these habitats recover faster if oil is dispersed before it reaches these areas.[10] Thus, the primary biological benefits of dispersant use are to reduce the hazard to birds (unless the dispersant is sprayed directly on them) and to prevent oil from stranding on shorelines. Sometimes, it may be more the aesthetic value that is protected, particularly if stranded oil is removed from beaches and rocky shorelines by high-pressure hot water at the sacrifice of the local biological communities.

Further advantages of using dispersants in combating a large oil spill are that they can be rapidly deployed (by aircraft) over a large area, may be used when sea conditions preclude mechanical response, and, if successful, can be a very cost-effective oil spill countermeasure. Dispersants can be applied by either fixed wing aircraft, helicopters, or systems installed on a vessel. The most efficient system for large spills is the Airborne Dispersant Delivery System, a portable unit developed for use on any available C-130. Dispersants are most effective when they are applied early, because the oil becomes less dispersible as its viscosity increases. However, dispersants that are effective on higher viscosity oils are being developed. The major consideration in applying the dispersant is to achieve a relatively uniform application on the oil without undue wind drift loss. Most dispersants require an application of dispersant to oil in a ratio of about 1:10 to 1:20. As with mechanical equipment, prepositioning of dispersants is necessary to achieve an early and effective response.

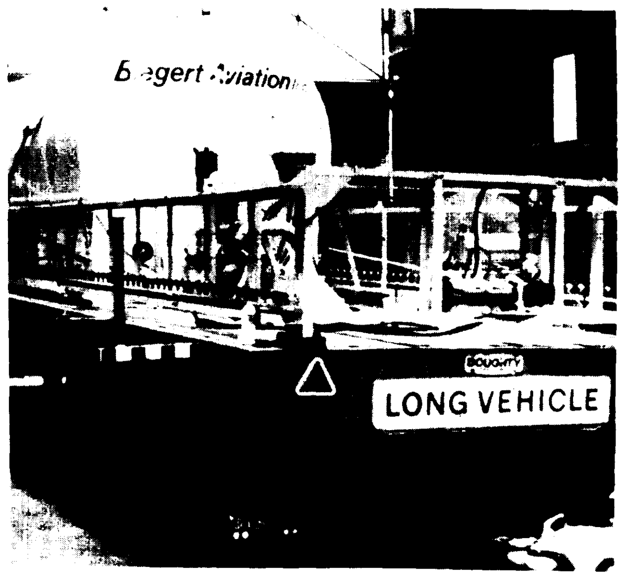


Photo credit: Jim Mm/kc

Airborne Dispersant Delivery System, or ADDS pack, seen mounted on a flatbed for easy transport to a C-130 airplane.

In a major study published in 1989, the National Research Council generally approved the use of dispersants and recommended that they be considered as a potential first response option along With mechanical cleanup.[11] Mechanical cleanup has the advantage of removing oil from the marine environment (although, thereby, creating a waste disposal problem onshore) but is generally limited by inability to cover a large slick area in a reasonable period of time. Dispersants are one of the few countermeasures that can be applied to a large area in a timely manner. One other question surrounding dispersants, however, is the

[10] Ibid., p. 4.

[11] Ibid.

lack of hard data about their effectiveness in actual spill conditions. The National Research Council recommended further research in this area. One difficulty, in particular, is in establishing a methodology for determining dispersant effectiveness at sea.

How well dispersants work depends on sea conditions and application techniques as well as on the chemical nature of both the dispersants and the oil. A certain amount of wave energy is desirable to achieve mixing, whereas a calm sea reduces the immediate effectiveness of dispersants. Improvements have been made in application techniques, but they still appear short of being routinely optimal. Further gains could be made from research in this area.

BURNING, BIOREMEDIATION, AND OTHER TECHNIQUES

In Situ Burning

In situ burning is the process of burning an oil spill in place either with or without the use of fire containment boom. In order to ignite oil on water, the oil must be relatively fresh, and the slick must be at least 3 millimeters thick. To ensure thickness and to isolate oil from contact with a stricken vessel or other object, fireproof booms may be used. Since the more volatile components of spilled oil immediately begin to evaporate, there is less potential for successful in situ burning as the slick ages. Some oil residue (about a 1 millimeter thick layer) will remain in the water after burning oil because the flame is always quenched by heat losses to the water surface when the oil layer gets thin. Such residue is itself a problem to clean up, but burn efficiencies of over 90 percent can be obtained, particularly if the oil is confined with booms or other means to keep the oil layer as thick as possible. Since less evaporation takes place in cold regions, in situ burning maybe more successful in these areas.

Several techniques have been devised for igniting oil spills. Devices used include floating igniters that can be deployed by air and the helitorch igniter, which is a tank system containing gelled gasoline suspended on cables below a helicopter. One device under design is a laser ignition system using two coupled lasers from a helicopter to heat and ignite oil spills.

Burning has been used in response to accidental oil spills with varying success. The use of burning to remove oil from the water produces a trade-off that must be evaluated by local authorities. The trade-off is between removing oil from the water and releasing the products of combustion into the atmosphere. Measurements thus far indicate that combustion products released into the atmosphere are no more hazardous than those released by evaporating oil, and that the total environmental loading of toxic components remains the same or is reduced by the combustion of crude oil spills on water.[12] Burning produces black sooty smoke that is a highly visible pollutant and may raise concerns about human health effects, whereas oil on the surface of the water, while also polluting in terms of volatiles entering the atmosphere, is usually perceived by the public to be less threatening to human health.

The aesthetic trade-off is not only one of ocean v. atmosphere, but also one of time frame, the short-term impact of smoke and combustion products versus the longer-term impact of an oiled shoreline. The major incentive to burn the oil is not only to remove it

[12] David D. Evans, "In-Situ Burning of Oil Spills," Alaska Arctic Offshore Oil Spill Response Technology Workshop Proceedings, U.S. Department of Commerce, National Institute of Standards and Technology, NIST Special Publication 762, April 1989, p. 53.

from the water but to reduce the probability of its becoming stranded on shore.

In some circumstances (e.g., if oil is not isolated from the vessel that spilled it) burning could put a stricken vessel, its remaining cargo, and any personnel still on board at risk. The intentional sacrifice of a vessel and its cargo *may* ultimately cost less than the total cost of a spill that could not be controlled, but this is rarely obvious at the time a response decision must be made. The decision to deliberately set fire to a vessel is one that most people would be very reluctant to make, especially if considerable oil remains on board and if there appear to be other response options. In the case of the Exxon *Valdez,* much more oil remained on the ship than was spilled. Most of this oil was successfully offloaded, thereby averting the greater tragedy that would have occurred if this oil also had spilled. Even so, Exxon's total costs to fight this spill greatly exceeded the value of the ship and its cargo.

Bioremediation

Bioremediation is the in situ use of microbes to biodegrade and oxidize hydrocarbon molecules. Biodegradants can be marine bacteria naturally occurring in the spill area, nonindigenous naturally occurring bacteria, genetically engineered microbes, and nutrients that can be added to enhance biological oxidation. Tests of this technique on water have shown little or no enhancement over the naturally occurring biodegradation.[13] Use of bioremediation on impacted shorelines, however, has apparently been successful in some cases. Exxon, in conjunction with the Environmental Protection Agency (EPA), recently conducted a large-scale test of this technique in cleaning up beaches soiled by the *Exxon Valdez* spill. About 70 miles of shoreline were coated with two kinds of nitrogen- and phosphorus-bearing fertilizers to boost indigenous bacterial populations.[14] Initial results are inconclusive, but the data are still being evaluated. One difficulty is measuring the effectiveness of the technique.

Proponents of bioremediation say it is potentially the least damaging and least costly of cleanup techniques, particularly for soiled beaches. Its use on water, however, would appear to be limited except perhaps as a follow up to other actions. The major disadvantage of bioremediation is the long time frame involved. On beaches where it could take 5 to 7 years for oil to breakdown under natural conditions, bioremediation with fertilizer could reduce that to 2 to 5 years.[15] Research needs to be conducted on the effect on local habitat from increased microbial populations and nutrient levels. Efforts to engineer new microorganisms or to identify and cultivate more efficient ones may be promising.

Miscellaneous Chemical Agents

Gelling Agents

Gelling agents change liquid oil into a solid to aid in recovery or are directed toward tanker accidents where pollution might be avoided or diminished by gelling the oil remaining in the tanks. Gelling agents require mixing with oil and allowing adequate time for the gel to set. Some gels set in a matter of minutes, whereas others, depending on environmental conditions, require about 8 hours to form modest strength and several days to form substantial strength. Field tests have shown that large amounts of gelling agent

[13]Fingas, op. cit., footnote 7, p. 30.

[14]Mark Crawford, "Exxon Bets on Bugs in Alaska Cleanup," *Science,* vol. 245, Aug. 18, 1989, p. 704.

[15]Ibid.

may be required, up to 40 per cent of the volume of the oil itself.[16] For these reasons gelling agents are not generally stocked for use by spill responders.

Herding Agents

Herding agents are designed to contract a spill and keep it from spreading. Herding agents are limited in effectiveness and are more successful in controlling small, thin slicks. Tests and actual use of these products showed that utility was limited to very calm waters. Due to their limited application and operating spectrum, there is little remaining use of herding agents at this time.

Sinking Agents

Sinking agents, such as hydrophobic chalk, have been used to prevent oil from reaching shore. The French used about 3,000 tons of powdered chalk to sink an estimated 20,000 tons of oil following the 1967 Torrey Canyon spill. Very little sunken oil came ashore. However, Canadian tests of several sinking agents have shown that none were effective in holding oil after the initial sinking and that it slowly leached back to the surface over a few days.[17] Because the sinking mass causes suffocation of bottom life and also exposes many bottom-dwelling organisms to oil, sinking agents are generally forbidden by environmental regulatory agencies.

Combustion Promoters

Burning agents have been developed to assist in the combustion of oil, but these generally have not functioned well in actual practice. Burning agents are of two generic types, sorbents and pyrotechnical compositions. Sorbents function by collecting oil in thicker masses to assist in burning, and pyrotechnical compositions keep the slick burning. Burning agents are of limited use because of the large amount of material needed for a beneficial effect and by the fact that in situ burning can be accomplished without them.

QUANTITY AND DISTRIBUTION OF RESPONSE EQUIPMENT

Although oil spill response equipment is widely distributed around the United States, the availability of equipment for responding to major spills is limited. Principal stocks are held by the U.S. Navy, the U.S. Coast Guard, and industry cooperatives.

The Navy has two major equipment depots, one in Williamsburg, Virginia the other in Stockton, California. A small amount of equipment is located in Pearl Harbor, Hawaii. The primary mission of Navy resources is to fight spills from Navy ships and facilities; however, its equipment is considered a national resource, and, as in the case of the *Exxon Valdez* spill (in which equipment from both major Navy depots was used), may be called on in emergencies. The Navy has invested a total of approximately $30 million for its equipment. Since much of this equipment was purchased in the mid-1970s, its replacement value would be much greater than this (rough estimates are over $100 million). Navy equipment currently constitutes the largest equipment stock available in the United States applicable for fighting large, offshore spills. The principal Navy countermeasures equipment are 24 Navy-modified belt skimmers, each with a capacity of about 250 gallons per minute. These skimmers were used in the *Exxon Valdez* spill, but were no match for the huge volume of oil to be recovered. They

[16] Fingas, op. cit., footnote 7, p. 29.

[17] Ibid., p. 31.

Photo credit: U.S. Coast Guard

U.S. Navy Marco Class V skimmer deployed in Prince William Sound.

Photo credit: US. Coast Guard

Dracone fuel bladder used for temporary storage of recovered oil.

are also not capable of effective recovery in rough seas (above sea state 3). The Navy has no dispersant capability. A potential constraint to efficient operations is that the Navy must depend on outside contractors for off-loading recovered oil, as it has no tank barges of its own. Appendix B contains an inventory of the Navy's principal resources.

The U.S. Coast Guard also maintains two important equipment stocks, one at its Atlantic Strike Team base in Mobile, Alabama, the second at its Pacific Strike Team base at Hamilton Air Force Base, California. Three Strike Teams were maintained until 1987, when the Atlantic and Gulf Strike Teams were consolidated due to budget constraints. Coast Guard stocks include a number of Open Water Oil Containment and Recovery Systems, the principal elements of which are skimming barriers, pumps, and storage bladders (dracones). This equipment is not sufficient to combat a major spill. The Coast Guard relies on private contractors for additional mechanical cleanup equipment. A significant amount of equipment at the two Coast Guard Strike Team bases is devoted to the important mission of off-loading (lightering) stricken vessels to minimize the loss of oil. The Coast Guard has about 20 Air Deliverable Anti-Pollution Transfer Systems for this purpose. Appendix B contains a summary of Coast Guard stock.

Much of the rest of the available oil spill response equipment in the United States is maintained by industry oil spill cooperatives. There are approximately 93 of these cooperatives in the United States (see app. B), but virtually all are designed for fighting spills in protected harbors, sheltered waters, and inland areas.[18] According to the American Petroleum Institute's recent Task Force Report on Oil Spills, "no U.S. cooperative has been designed to deal with a catastrophic spill."[19] Moreover, little of the available industry equipment would be applicable for more rigorous offshore conditions. Cooperative and other equipment that could be suitable offshore is listed in appendix B, as is a listing of the Alyeska Cooperative's recent acquisitions.

The largest oil spill cooperative in the world is the Oil Spill Response Ltd. (OSR) base in Southampton, England. The base is equipped

[18] American Petroleum Institute, "Task Force Report on Oil Spills," June 14, 1989, p. 10.

[19] Ibid.

with the capability to respond to large offshore spills. (Because Exxon is a full member of this cooperative, it was able to use 50 percent of the equipment on hand at the time to fight the Exxon *Valdez* spill. OSR base equipment was among the first out of state equipment to arrive in Prince William Sound.) The base has been stocked with the intent to be able to respond simultaneously to two 10,000-ton spills (two 3-million gallon spills).[20] Whether this capability could be met in practice is difficult to determine. *In general,* such estimates of response capacity typically depend on the manufacturer's estimates, and such information may be overstated and applicable primarily to ideal conditions. OTA estimates that the capability of the Southampton cooperative is roughly equivalent to that of one of the U.S. Navy depots. OSR base equipment is also listed in appendix B.

The industry has proposed to remedy the lack of equipment for fighting major spills by establishing five regional oil spill response centers and equipping each with the capability to respond to a 30,000-ton spill. Each Petroleum Industry Response Organization (PIRO) center would contain lightering equipment, booms, skimmers, dispersant equipment, and other ancillary equipment, and would be manned by oil spill professionals. The estimated capital cost for each center would be roughly $24 million in 1990 dollars. Although PIRO claims that this amount will enable its response centers to cope with 30,000-ton *(9.2* million-gallon) spills, these claims have yet to be evaluated by an independent organization. It is thus not certain whether response funding will be adequate. The Navy, for instance, estimates that each of its 2 major depots have equipment whose replacement value is about $50 million, and this equipment provided only a limited capability to respond to the *Exxon Valdez* spill. Nevertheless, it is difficult to evaluate response center capabilities by comparing equipment costs alone. Variables such as equipment maintenance, training, and logistics plans are also very important. Proposed regional center capital equipment is presented in appendix B.

In sum, the only significant stock of oil spill response equipment that is readily available, tested, and maintained for fighting a large offshore spill in the United States is that of the U.S. Navy. In Europe, the large industry cooperative at Southampton has a significant capability roughly equivalent to one of the two Navy depots. Other industry capabilities in the United States are either insignificant or not readily available for offshore spills. The API/PIRO proposal for establishing new equipment depots in the United States at strategic locations will significantly improve industry capabilities. However, it is still uncertain whether PIRO would be capable of recovering significant portions of a large offshore spill. It also appears that the funds proposed to be allocated by PIRO may be inadequate for the goal.

[20] A proposal has been made t. expand the OSR base so that it will be capable of handling two 30,000-ton spills. M.D. Long, Assistant Manager, Oil Spill Service Centre, personal communication, Jan. 22, 1990.