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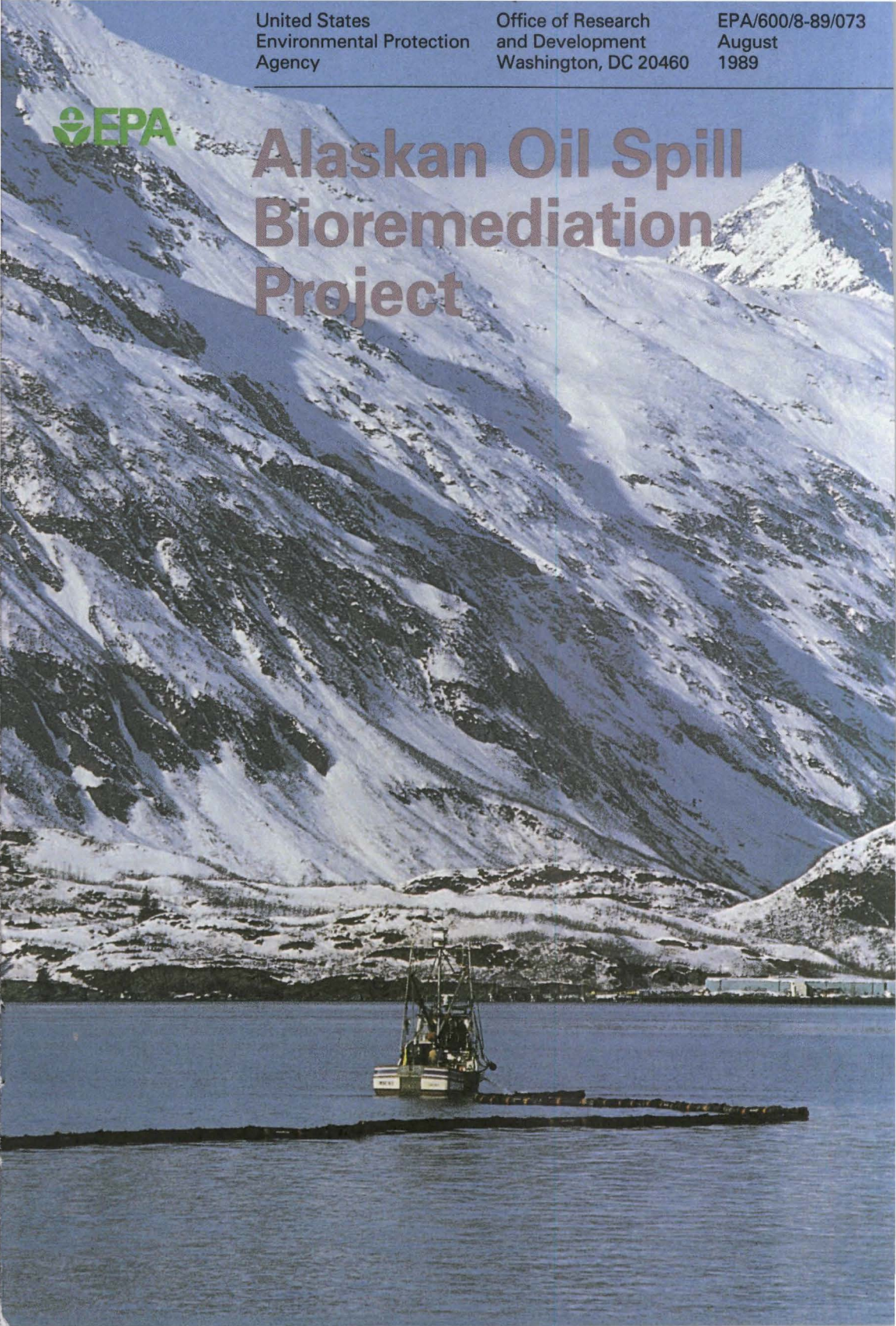
EPA

Alaskan Oil Spill Bioremediation Project



ALASKAN OIL SPILL BIOREMEDIATION PROJECT

A few minutes after midnight on March 24, 1989, the 987-foot tanker *Exxon Valdez* ran aground on Bligh Reef in Prince William Sound, Alaska. Approximately 11 million gallons of crude oil flooded one of the nation's most pristine and sensitive environments in less than 5 hours. As part of the effort to clean up the spill, the U.S. Environmental Protection Agency's Office of Research and Development initiated a "bioremediation" study to determine the feasibility of using nutrients to enhance microorganisms to degrade oil on the shorelines of Prince William Sound. A major portion of this venture was supported financially by the Exxon Company. The study demonstrates that bioremediation is a powerful tool for reducing the detrimental effects of crude oil and other chemical spills. As a result, this innovative technology holds great promise for more timely and effective cleanup of future oil spills, and marks a significant step forward in oil spill research and remediation.

Energy and the Environment

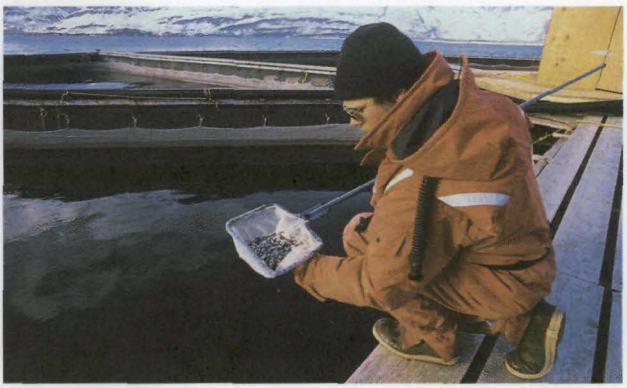
Americans use about 700 million gallons of oil every day. This large energy demand, coupled with a limited domestic supply, has required the United States to import significant quantities of oil to meet our energy needs. Alaskan oil, which represents 25 percent of our total domestic oil production, helps to limit the nation's dependence on imported oil. However, as dramatized by the *Exxon Valdez* tanker accident, spills during transportation of this vital resource can result in devastating effects on our natural environment.

The *Exxon Valdez* spill occurred off the coast of Bligh Island in Prince William Sound on March 24, 1989. Prince William Sound and its islands contain over 2,000 miles of shoreline. This pristine environment, which is bordered by national forests, is home to a wide range of wildlife, including caribou, grizzly bears, deer, gray wolves, seals, sea lions, otters, and whales, as well as an extensive array of birds. Many commercial fish hatcheries are also located in the protected bays ringing the Sound. These hatcheries produce salmon, Pacific herring, halibut, sablefish, crab, and shrimp. The oil spill has damaged a significant portion of the area's diverse wildlife, and directly affected the lives of many Alaskans.

Environmental safeguards must be established to prevent or mitigate similar tragedies. Federal agencies have begun studies and investigations to strengthen both prevention and preparedness. In addition, Congress is investigating legislative remedies. The U.S. Environmental Protection Agency (EPA) Administrator will also coordinate long-term planning to restore the environment of Prince William Sound and other affected areas. This work is expected to yield important knowledge concerning the long-range environmental impacts of oil spills and ways of ameliorating them.

Prevention is the best defense, but because it may be impossible to completely prevent spills, research is needed so that new, more advanced cleanup techniques

Fishermen deploy an oil boom to protect the region's rich herring and salmon hatcheries. An estimated 4,000 fishermen work in the area now affected by the spill.



can be examined and tested. A Report to the President prepared by the National Response Team calls for both public and private research to improve current cleanup technology. The *Alaskan Oil Spill Bioremediation Study* is an important step in this direction. The knowledge gained from this study will enhance the cleanup efforts underway in Prince William Sound, and help to ensure more timely and effective remediation of future oil spills in marine environments across the world.

Magnitude of the Spill

The *Exxon Valdez* tanker accident has resulted in the most massive oil spill in U.S. history, and the first big spill to foul the cold waters off Alaska's coast. Patches of oil or oil-and-water emulsion (globules of oil suspended in water) have spread over 3,000 square miles and onto an estimated 1,000 miles of shoreline (including 350 miles in Prince William Sound alone). In contrast, only 240 miles of coastline were affected when the *Amoco Cadiz* broke up on rocks in the stormy seas off France's Brittany Coast in 1978. In that spill, 68 million gallons of oil were released into the ocean.

The severity of an oil spill's effects on the environment varies greatly and depends upon many conditions, including:

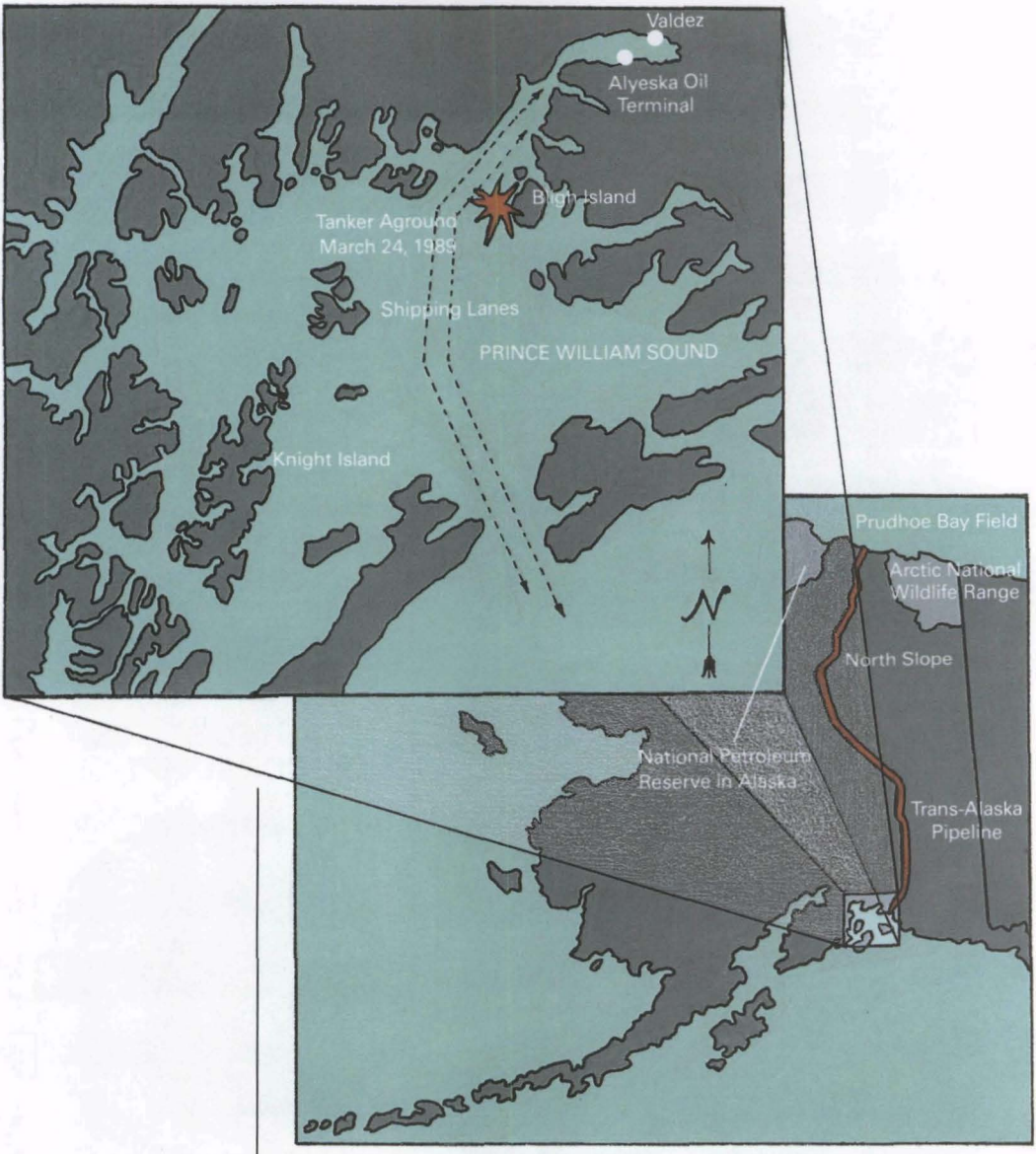
- The type and amount of oil involved.
- The degree of weathering.
- The geographic location.
- The time of year.
- The types of plant and wildlife habitats affected.
- The life stage of the affected organisms, and their sensitivity to contamination.

By 1984, Brittany's environment had largely recovered from the effects of the spill and ensuing cleanup operations. It is too early to tell if Prince William Sound will be as resilient. However, a number of

UNITED STATES OIL CONSUMPTION

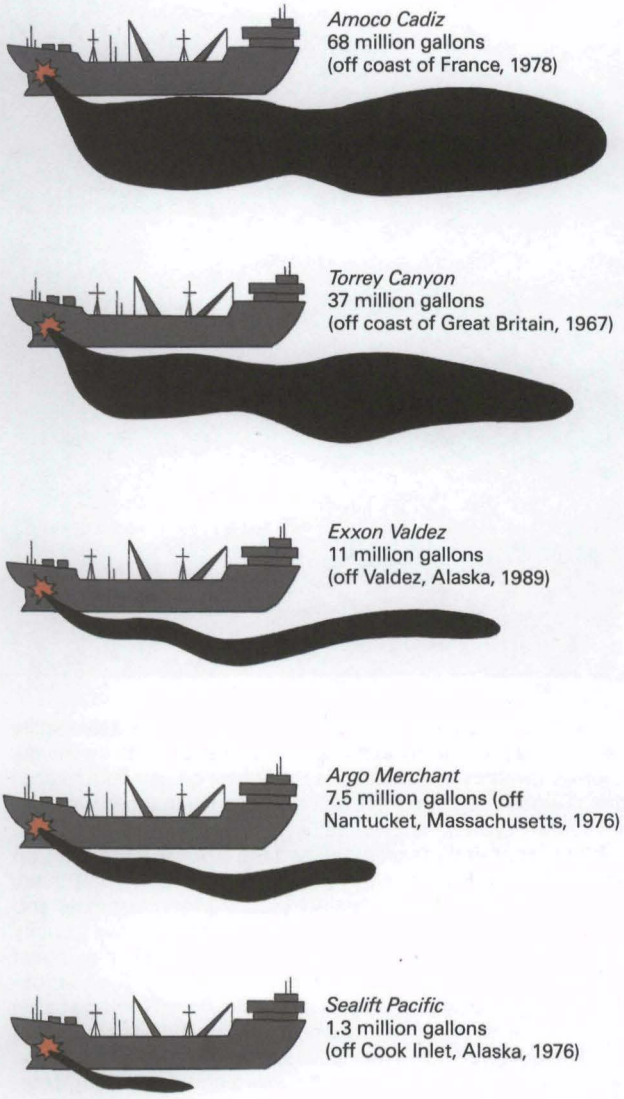
Source: U.S. Energy Information Administration, *Monthly Energy Review*, March, 1989, pp. 50, 57.

ALASKA AND PRINCE WILLIAM SOUND



ALASKA — The name comes from an Aleutian word meaning "great land." If laid on the 48 lower States, Alaska would cover nearly one-fifth of them. The State is great in resources as well as land mass. In 1968, enormous quantities of oil were discovered on Alaska's North Slope in Prudhoe Bay. In 1974, construction began on the Trans-Alaska Pipeline under the direction of the Alyeska Pipeline Consortium Co., which was formed by the seven firms that pump crude oil from the North Slope. The pipeline extends nearly 800 miles with its terminus in Valdez, Alaska, where a shipping complex and other facilities are located. Since the pipeline was built, nearly 9,000 shipments of oil have been transported through Prince William Sound.

MAGNITUDE OF OIL SPILLS ACROSS THE WORLD



Source: U.S. Environmental Protection Agency's Office of Research and Development, *Research Summary: Oil Spills*, February 1979, p. 2.

elements have combined to make the *Exxon Valdez* oil spill more difficult to contain and clean up than the accident in Brittany. These include the remoteness of the area, the extreme weather conditions, and the lack of preparedness for such a massive cold-water spill.

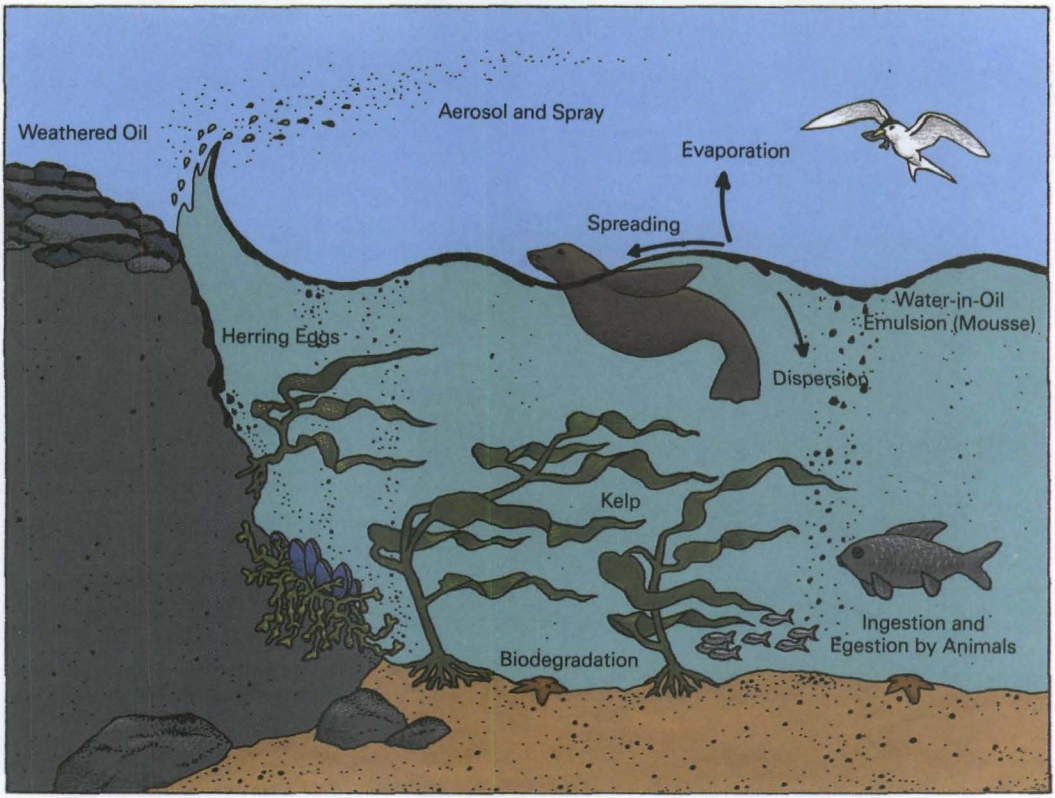
The spill occurred in a remote location, and as the oil spread, it moved to even more difficult and inaccessible areas. The town closest to the spill site is Valdez, which has a population of less than 4,000 residents. Weather also affected the pace and effectiveness of the oil recovery. Severe weather and gale force winds suspended operations a number of times, forcing vessels to tow cleanup equipment to sheltered harbors and coves.

The habitats of the south-central Alaskan coast also are more vulnerable to spilled oil than those of more temperate climates, such as Brittany's, because subarctic temperatures and resulting slower rates of physical weathering and degradation allow the oil to persist. In addition, oil stranded on some beaches with low tide or wave action may remain for several years. Thus, in addition to the short-term, acute effects (such as wildlife mortalities) caused by the oil, there is potential for long-term, sublethal chronic effects such as habitat and food chain disruption, as well as decreased survivability and reproductivity of animals exposed to the oil. These effects, while perhaps not immediately fatal to a given individual, have a direct bearing on the survival of a species as a whole and consequently on the balance of the ecosystem of which it is a member.

Physical Cleanup

Oil spills, even small ones, are difficult to clean up. The type of cleanup technologies used varies according to the location of the spill, the nature of the oil, the weather, and the natural resources present. One of the primary concerns in selecting a cleanup method is to choose

BEHAVIOR OF OIL IN PRINCE WILLIAM SOUND



WHERE DOES IT GO? The recovery rates of crude oil due to massive spills have typically been low. Winds and waves help spread and disperse the oil, some of which then evaporates into the air. As the lighter components vaporize, the rest of the oil weathers into a thick black substance that can wash up on beaches or sink to the ocean floor. Eventually, this weathered oil degrades. In the meantime, it may contaminate plankton and the small fish that feed on these microscopic marine organisms. In turn, larger animals in the food chain, including humans, may eat the contaminated fish. Marine mammals and birds may also be exposed directly to floating oil in the water. Oil has a sticky consistency that causes it to adhere to fur and feathers. Animals may ingest the oil through grooming; sea otters also may freeze to death if their fur becomes coated with oil. Herring eggs are also vulnerable to oil. Herring spawn in the spring months, and their eggs may be smothered by the oil spill and die outright. If the eggs do survive, the oil may cause abnormalities in the growing embryos. Should the oil persist in spawning areas, it could have long-term impacts on the herring population.

Source: National Response Team, *The Exxon Valdez Oil Spill: A Report to the President from Samuel K. Skinner, Secretary, Department of Transportation and William K. Reilly, Administrator, U.S. Environmental Protection Agency,* May 1989.

one that will not cause greater harm to the environment than the oil itself. Exxon, along with the State of Alaska and the various Federal agencies involved in the cleanup, have used a number of techniques to clean up the floating oil. More than 10,000 individuals are involved in these efforts. Specialized equipment, barges, and several hundred vessels and aircraft have also been deployed to aid in the cleanup.

Most of the floating oil in Prince William Sound has disappeared, leaving shorelines as the main point of contamination. On many beaches, the oil has weathered into a thick, black layer that has settled into the fine beach gravel and covered rock surfaces and cliffs.

High- and low-pressure spraying, steam, manual scrubbing, and raking of congealed oil have all been used to remove oil from the surface of rocks and beaches. These techniques, however, cannot effectively remove all of the oil on the surface of the beaches, or oil that is trapped under the rocks and in the matrix of sediments. This is where bioremediation is especially useful.

Shortly after the spill, a bird rescue operation was begun. Cormorants, eagles, loons, and ducks were among the birds brought to the cleaning and rehabilitation center established in Valdez.

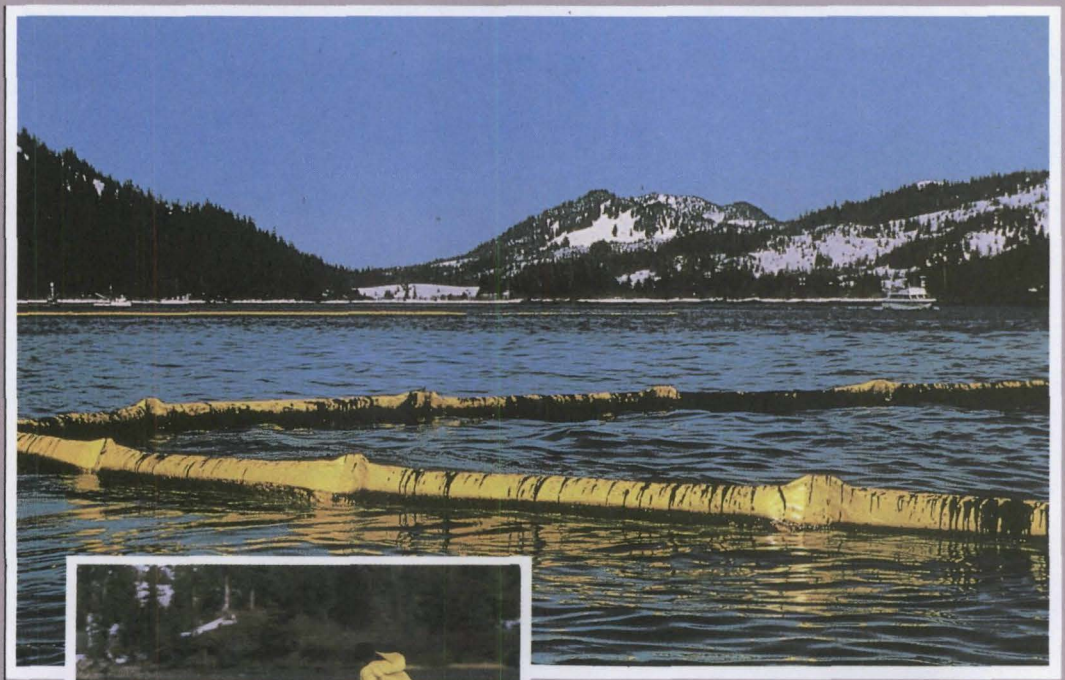
Bioremediation

Bioremediation involves the use of microorganisms (such as bacteria) to mitigate the effects of oil and other types of chemicals. The process used in Alaska relies on the ability of naturally occurring microorganisms to degrade or break apart toxic hydrocarbons (such as those found in crude oil) in marine or other aquatic environments. Because it does not involve physical disruption of the site, bioremediation is an especially desirable technology for oil spill remediation.

For several years, the EPA Office of Research and Development (ORD) has been studying the microbial degradation of oil as part of its long-term research program. Until the *Exxon Valdez* accident, however, no microbial treatment processes had been developed for use in remov-

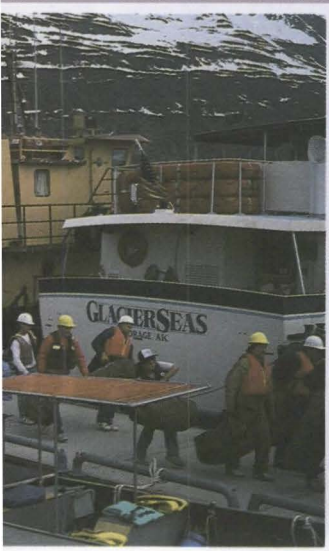
Conventional Cleanup Methods

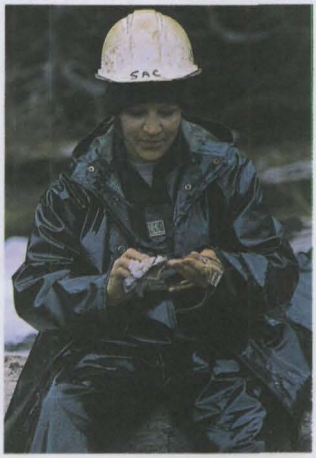
- **Dispersants** — Chemical solutions designed to reduce the cohesiveness of oil slicks so that the petroleum breaks up into droplets and becomes diluted in the water. In order to break up the film, dispersants must be able to mix into the oil and be agitated (like detergent in a washing machine). This mixing energy can come from the environment, such as heavy seas and surf; the application technique, such as aerial spraying by airplanes and helicopters; and the dispersants themselves, some of which are self-mixing. Dispersants are most effective on spilled oil that has not weathered.
- **Booms** — Physical barriers that contain, deflect, or absorb oil. Booms are used to prevent oil from reaching an environmentally sensitive area.
- **Skimmers** — "Marine vacuums" that suck up crude oil. The oil is then transferred to dredging barges. It is difficult for skimmers to work when oil weathers and becomes too thick for a skimmer's pumps. Kelp can also clog the pumps.
- **Burning** — A flammable substance applied to oil is corralled by booms and ignited. Burning creates residual smoke that may cause irritation to nearby residents, and it can only be performed in favorable weather.



Booms have been used in Prince William Sound to contain the oil and prevent it from reaching environmentally sensitive areas. Fence booms (above) are constructed from rigid or semi-rigid material and serve as a vertical barrier against oil floating on water. Curtain booms (left) have a flexible skirt that traps the oil; the skirt is held down by ballasting weights or a separate tension line.

Workers used high-pressure spraying to clean up greasy rocks. Booms corral the sprayed oil, which is pumped to a recovery vessel.





More than 10,000 individuals took part in the cleanup effort (left); a worker scrubs an oiled rock (above).

EPA'S Science Advisory Board

The Science Advisory Board (SAB) was established in 1978 by Congress under the Environmental Research, Development, and Demonstration Authorization Act (42 U.S.C. 4365). The objective of the SAB is to provide advice to the EPA Administrator and other Agency officials on the scientific and technical aspects of environmental problems and issues.

The SAB is composed of engineers and scientists who are recognized experts in their respective fields. These individuals are drawn from academia, industry, and environmental communities throughout the United States, and in some cases, other countries. The SAB conducts its business in public view and benefits from public input during its deliberations. Through these proceedings, Agency positions are subjected to critical examination by leading experts in the field in order to test the currency and technical merit of those positions.

The SAB's Executive Committee serves as the focal point for the coordination of scientific reviews by the Board's standing committees. Historically, five committees have conducted most SAB reviews: 1) the Clean Air Scientific Advisory Committee; 2) the Environmental Effects, Transport, and Fate Committee; 3) the Environmental Engineering Committee; 4) the Environmental Health Committee; and 5) the Radiation Advisory Committee. In addition, two other committees were recently formed: the Indoor Air Quality/Total Human Exposure Committee and the Research Strategies Advisory Committee. These seven committees perform various functions, including reviewing documents, guidelines, and research activities; conducting workshops; and working with ad hoc committees.

The Environmental Effects, Transport, and Fate Committee reviewed ORD's research plan for the *Alaskan Oil Spill Bioremediation Project* before the field test began, and commended ORD for its rapid response. The Committee also pointed to the need for research regarding the ways bioremediation could be applied to spills and inadvertent discharges of chemicals into the environment. The Committee believed that EPA's project would be a significant contribution to future research planning and technology development.

"The Alaska oil spill tragedy demonstrated the primitive state of our oil spill cleanup procedures and technologies – and the need to develop and encourage the use of innovative cleanup techniques such as bioremediation."

– William K. Reilly, Administrator of the U.S. Environmental Protection Agency

ing crude oil from contaminated beaches. ORD staff suggested that bioremediation might be useful in enhancing the natural degradation processes in Prince William Sound. The Acting Assistant Administrator of ORD convened a panel of over 30 national and international expert scientists in the field of bioremediation to determine the feasibility of using this technology in Alaska. The panel recommended that ORD plan and conduct a field demonstration test to determine if bioremediation would be useful in cleaning up the oil.

Because of the importance of quick action, ORD went forward with establishing a field office in Valdez soon after the spill. ORD staff also developed a draft research plan that was reviewed by EPA's Science Advisory Board. On June 2, 1989, ORD entered into a cooperative agreement with Exxon to test the capability of bioremediation in treating contaminated beaches in Prince William Sound.

Bioremediation is expected to have beneficial effects on the Alaskan shoreline in both the near and long term. For example, certain toxic components of the oil can be quickly degraded, making them less available to marine organisms.

"Bioremediation is a potentially powerful approach to reducing the time required to decrease the environmental effects of oil and other chemical spills."

– Erich Bretthauer, EPA's Acting Assistant Administrator for the Office of Research and Development

Also, animals and plants that live in the area will be exposed to fewer toxic components of the oil than they would without bioremediation.

EPA estimates that without bioremediation, it would take at least 5 to 10 years to degrade oil on the Alaskan shoreline. With bioremediation, this period may be cut in half to as short as 3 to 5 years. It will, however, take many more years before all the effects of this oil spill are no longer detectable in Prince William Sound and surrounding areas.

The Alaskan Oil Spill Bioremediation Study

The major portion of the Alaskan Oil Spill Bioremediation Project involves a field test to determine if adding fertilizer to contaminated beaches will effectively stimulate native bacteria to break down the oil. Scientists have determined that hydrocarbon-degrading bacteria do live in the waters and sediments of Prince William Sound. However, even in the presence of large amounts of petroleum, their growth is limited by the availability of nutrients (nitrogen and phosphorus), which are essential for bacteria to utilize the hydrocarbons as a food source. To overcome this obstacle, scientists have added fertilizer to selected test beaches in Prince William Sound to enhance microbial growth. The rationale behind this approach is that the more microorganisms there are available to break down the oil, the faster the rate of degradation.

Site Selection and Preliminary Testing

Before the test could begin, scientists had to select a suitable test site. The Alaska Department of Environmental Conservation, the National Oceanographic and Atmospheric Administration, and the Seattle EPA Regional Office provided recommendations for the demonstration site. ORD surveyed oil-contaminated

Summary of Agreement with Exxon

ORD and Exxon have signed a cooperative research and development agreement under the authority of the Federal Technology Transfer Act (FTTA) of 1986 (Public Law 99-502, October 20, 1986, U.S.C. 3710a). The FTTA encourages collaboration between Federal agencies, State and local governments, universities, and private industry to improve the economic, environmental, and social well-being of the United States.

Under the agreement, Exxon pays for all the costs of field operations directly applicable to the bioremediation study (these include local transportation by helicopter, planes, and boats; field and laboratory facilities; and subsistence for project participants). EPA pays and is responsible for oversight and management of the study. This will ensure the independence of study results. EPA has also agreed to provide supplemental resources for other efforts that are necessary to make the technology useful in cleanup of future spills. Exxon's contribution to the project is about $3 million; EPA's contribution is approximately $1.6 million.

The agreement also provides for an equitable handling of any inventions that may come out of the project. The party that patents an invention will pay the cost of prosecuting the patent. The patenting party also grants the other a nonexclusive, irrevocable license to use the invention both in the United States and abroad. Since either party can license any patented invention, the technology will be readily available to other groups needing it.

ORD scientists used helicopters to perform beach surveys of the contaminated shorelines.

beaches on foot and by using small boats, planes, and helicopters. After identifying several prime locations typifying Prince William Sound, test beaches were chosen on the southern shore of Snug Harbor, which is situated on the southeastern coast of Knight Island. The major features considered in selecting the site were:

- Reasonable uniformity of beach material (cobbles, gravels, or sands) and oil contamination.
- Adequate land size and topography to set up the needed number of test plots.
- Shoreline with a gradual slope.
- Minimal influence by freshwater (streams and snowmelt).
- Sufficient shelter from storms during the test period.
- Moderate levels of contamination to facilitate testing and measurements.

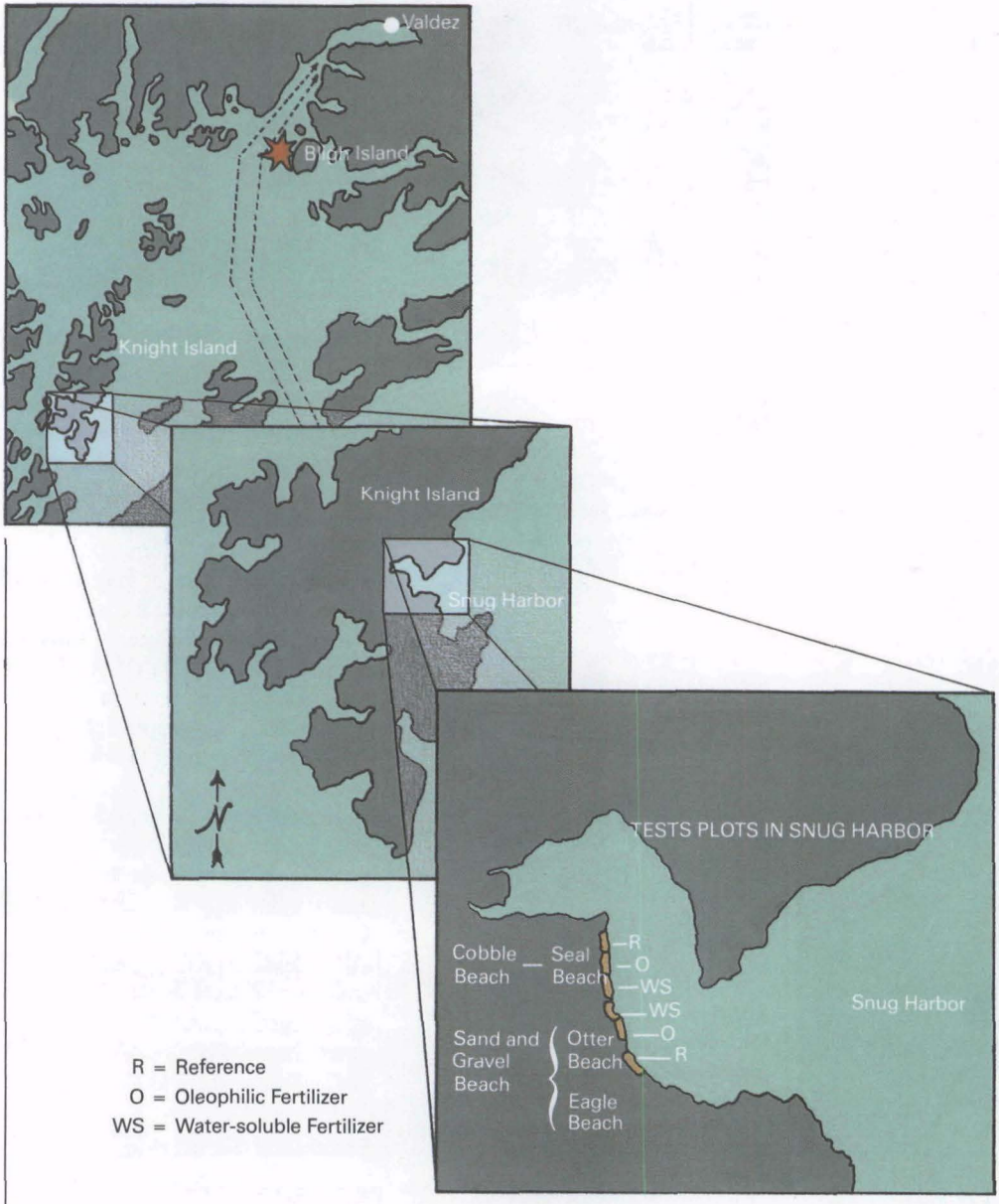
The test beaches selected on Snug Harbor best met these six characteristics.

A variety of preliminary laboratory and field tests were also conducted during this time. In the field, scientists gathered information about the composition of the spilled oil, the extent of contamination, the configuration of the shoreline, the presence of hydrocarbon-degrading bacteria, and the amount of nutrients available in the test area. Various types of fertilizers, application methods, and sampling procedures were also evaluated.

Nutrient Application

In early June, two types of fertilizer were applied to the selected test beaches in Snug Harbor: a water-soluble fertilizer (a typical garden fertilizer that releases nutrients as it slowly dissolves in water); and an oleophilic fertilizer (designed to adhere to oil). The water-soluble fertilizer, which was bagged in herring nets, was placed on the beach surface and anchored in the tidal zone with steel-reinforced rods. Rain and tides helped

LOCATION OF SNUG HARBOR



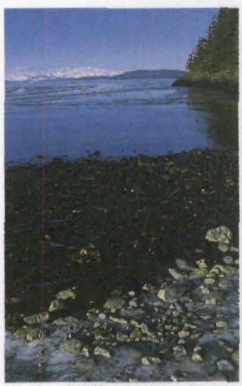
After 3 weeks of bioremediation treatment, a patch of cobblestone showed significantly less oil contamination on its surface.

disperse the nutrients to the oil-contaminated areas. The liquid oleophilic fertilizer was sprayed over the contaminated test areas.

Each fertilizer was applied to two types of beaches – one composed of mixed sand and gravel; the other made up of cobblestone. The application strategy was designed specifically to promote biodegradation of oil in both physically cleaned and untreated beach sediments. Two "reference" test plots, where no nutrients were added, also were set up for comparison against the treatment plots. The reference plots were physically separated from the treatment plots to ensure that no nutrients would move into these areas. In all, the six plots occupy approximately 2,000 square yards of beach area in Snug Harbor.

Sampling

Several sampling and field testing methods were used to observe changes in the composition of the oil, to monitor the movement of added nutrients in the test beaches, to detect changes in the number of bacteria present as the test proceeded, and to assess the degradation of the oil. The sampling permitted the scientists to determine if oil degradation was enhanced with no resulting harm to the ecology of the area.



Prince William Sound is edged with gravel and cobblestone shorelines; much of the oil that has washed up on these beaches has degraded into a thick, gooey layer.

Microcosms

Microcosms were constructed on board a fishing vessel to provide supplemental information to the field demonstration project. Microcosms are designed to simulate field operations, but on a smaller scale. They have the advantage of providing backup information in the event of a major storm or some other unforeseen complication that could result in lost field data. The microcosms also allow scientists to test bioremediation concepts under idealized conditions to better understand what may happen in the field.

Six tanks representing the six test plots were set up on the ship. Perforated containers filled with contaminated cobblestone and contaminated mixed sand and gravel were placed in the tanks. Then, water-soluble and oleophilic fertilizers were applied to simulate the test applications. Seawater was pumped into the tanks every 6 hours, and then withdrawn for 6 hours to imitate tidal cycles. The microcosms also received equivalent rain and sunlight as the field plots.

Ecological Monitoring

Ecological monitoring studies were conducted concurrently with the fertilizer application tests. Although dilution and tidal mixing should minimize the

potential for adverse ecological effects, EPA scientists have been monitoring the test plots for enrichment or toxic effects associated with fertilizer addition. For example, algal blooms (excessive growth of algae in a body of water) could occur as a result of the sudden availability of nitrogen and phosphorus. In addition, some of the byproducts of the degraded oil, as well as the oleophilic fertilizer, could be toxic to certain organisms living in the shoreline zone.

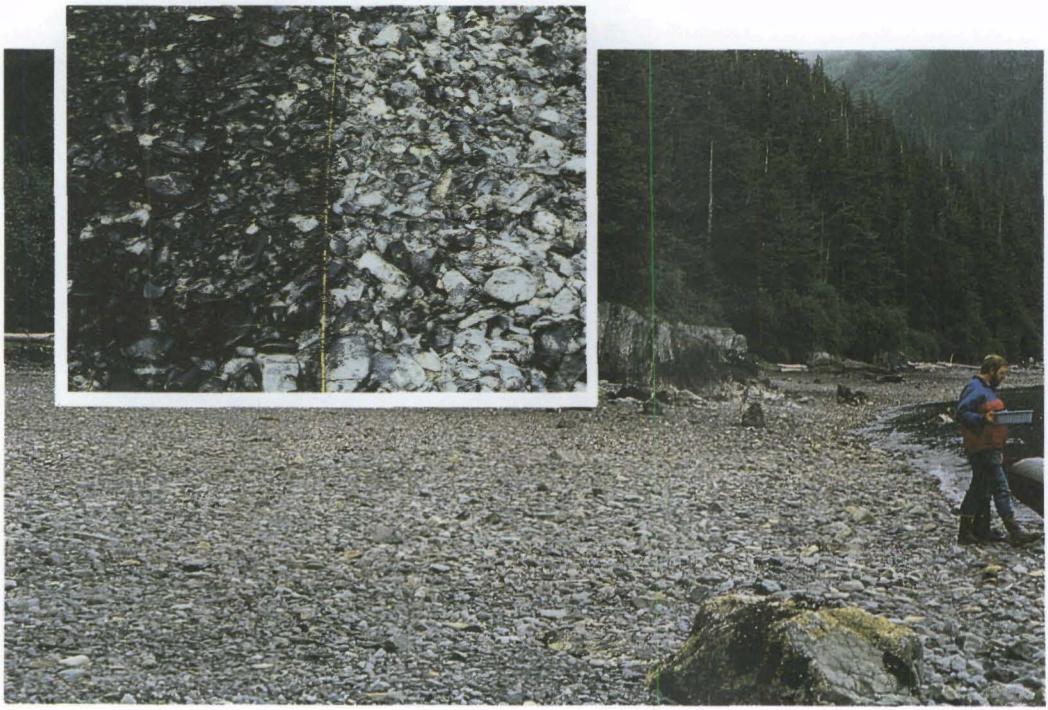
EPA monitored biological activity in the Snug Harbor waters to determine if the nutrients were causing algae to grow too rapidly. Also, 800 mussels collected from an uncontaminated beach northeast of Bligh Island were monitored for any accumulation of toxic substances in their tissue that may have resulted from the release or breakdown of the oil. Lastly, a wide range of native organisms (including mussels, Pacific herring, King salmon, algae, oysters, shrimp, mysids, and stickleback fish) was tested to determine the potential toxicity of oleophilic fertilizer to these species.

The Future of Bioremediation

As part of its cooperative agreement with Exxon, EPA agreed to provide information that would help the company decide whether to use bioremediation to clean up oil-contaminated shorelines in Alaska during the summer of 1989. By mid-summer 1989, all data were not available to make a definitive recommendation on the efficacy of bioremediation. However, given the significant potential positive benefits, the absence of adverse ecological effects, and the limited time remaining in the summer season in Alaska, EPA informed Exxon that the Agency would support a proposal for application of nutrients to Alaska's oiled beaches. EPA recommended specific procedures to maximize the technology's effectiveness. In the winter all cleanup activities, in-

An EPA scientist collects samples for laboratory analysis on the coast of Snug Harbor where the bioremediation field tests were performed.

Two field test plots show that a site where oleophilic fertilizer was applied is much cleaner than a site where no fertilizer was added. (Inset)



BIOREMEDIATION SCALE-UP: EPA'S RECOMMENDATIONS TO EXXON

EPA recommended the following procedures be carried out by Exxon when applying nutrients to oil-contaminated Alaskan shorelines.

- **Simultaneously apply the oleophilic and the slow-release, water-soluble fertilizers to oiled beaches wherever possible.** Preliminary information from ORD's field studies shows that the oleophilic fertilizer enhances the removal of oil from the surfaces of cobblestone and gravel. However, there is not enough evidence to demonstrate that the oleophilic fertilizer enhances the degradation of oil beneath large cobblestones and at any significant depth in the sediment. EPA believes that oil degradation in these beach areas would be enhanced by applying a slow-release, water-soluble fertilizer. The nutrients released from this fertilizer will be able to penetrate the less accessible areas through tidal flushing.
- **Clean up heavily and moderately oiled shorelines prior to nutrient application.** During the initial field studies, scientists observed that it took a long time for large globs of oil to degrade. Therefore, as much oil as possible should be removed from heavily and moderately contaminated shorelines before fertilizer is applied. For lightly oiled shorelines, physical cleanup is not necessary prior to nutrient applications.
- **Use a specific rate of fertilizer application.** To ensure the maximum amount of fertilizer is applied with the minimum impact on the environment, EPA has recommended specific rates of fertilizer application.
- **Initially apply the fertilizers on those oil-contaminated shorelines that are exposed to adequate flushing through the action of tides and wind to control algal blooms and toxicity.** The potential for algal blooms from the nutrients and toxicity to marine organisms from the oleophilic fertilizer are greatest in protected, poorly flushed waters. If sufficient flushing and dilution are questionable, EPA recommends that ecological monitoring be carried out along with the fertilizer application. If the monitoring results demonstrate any adverse environmental effects, the fertilizer application should be terminated immediately.

cluding bioremediation efforts, will be stymied by extreme weather conditions.

Based upon the results of ORD's research, Exxon proposed to begin bioremediation on nearly 6,000 yards of shoreline in Prince William Sound. Exxon's proposal was approved by the Regional Response Team, which provides expertise, equipment, and other resources in oil spill disasters such as the one in Alaska. The bioremediation application began on August 1, 1989.

A Delicate Balance

Alaska has been called upon to be both a source of energy for the United States and a seemingly endless frontier where nature is preserved. Actions are being taken to reduce the occurrence of oil spills, but in the event of a future spill — in Alaskan waters or elsewhere — it is hoped that the information gained from EPA's bioremediation project will be useful in enhancing the environment's natural ability to recover.