accumulate in the tissues of marine test species. In this environment, dilution, tidal mixing, and evaporation reduced the potential for significant impacts. In some low-energy environments (e.g., protected bays), greater impacts might occur. In other environments, the species present, water depth, and water temperature are all variables to consider in estimating potential impact. The effect of any impact of treatment, however, must be considered in view of the damage already caused by oil.

Evidence is also lacking that introduced organisms might be pathogenic to other life forms. In a series of experiments with North Slope crude oil, for example, researchers failed to find any significantly greater invertebrate mortality with bacterial seeding (or fertilization) than occurred with crude oil alone.[89] However, microorganisms to be considered as seeding candidates must be screened carefully to eliminate potential human or animal pathogens, including opportunistic pathogens such as *Pseudomonas* spp.

The possibility that introduced microbes might proliferate and upset the ecological balance appears to be of less concern. If effective at all, such organisms should die and be preyed on by protozoa once they have utilized the oil from a spill.[90] Of greater concern is that microbes introduced from other environments will not be able to compete as well as native species and will die *before they can* do their job effectively. EPA's Office of Pesticides and Toxic Substances has been developing procedures for evaluating the toxicity of biotechnology products. In concert with EPA's Office of Research and Development, it is establishing tests to evaluate the potential pathogenicity of nonindigenous microbes.[91]

Similar but greater concerns attend the introduction of genetically engineered organisms. Before such organisms are likely to be introduced to the marine environment (if they have a role to play at all), more basic knowledge of their potential impacts on that environment will be required, and regulatory officials and the public will have to become more familiar with biological mitigation techniques.

An additional concern is that although bacteria may break down the complex hydrocarbons contained in oil, they could leave behind products of partial biodegradation that are more toxic to marine life than the original constituents of the oil.[92] However, in time, intermediate products of possible concern, such as quinones and naphthalenes, are likely to be broken down further and thus unlikely to accumulate in the environment.[93]

bioremediation IN RELATION TO OTHER RESPONSE TECHNOLOGIES

Whether bioremediation technologies will be considered for use as primary or secondary response tools, or will be deemed of no use at all, will depend on the circumstances of each oil spill. All response technologies have the common purpose of minimizing the damage caused by a spill. How well a technology can accomplish this goal indicates its effectiveness. The perfect response technology has not been developed, and numerous uncontrollable variables may reduce effectiveness far below what it would be under optimal circumstances. As the size of a spill increases, for example, the difficulty of responding to it by any means grows. Adverse sea and weather conditions may greatly reduce the effectiveness of any open sea response. Even technologies that are adequate in some spill situations will be much less effective if they cannot be deployed, operated, and maintained easily.

Before bioremediation is likely to be considered as a response tool, it must be deemed not only effective for its intended use, but also more effective than traditional technologies. The effectiveness and safety of bioremediation technologies for responding to different types of spills have not yet been established adequately, and on-scene coordinators and other decisionmakers generally are not familiar with these technologies. Hence, most decisionmakers are reluctant to try bioremediation if other techniques could be effective. More traditional methods are preferred, and experimentation during

[89]R.M. Atlas and M. Busdosh, "Microbial Degradation of Petroleum in the Arctic," *Proceedings of the 3rd International Biodegradation Symposium*, Kingston, RI, August 1975, p. 85. The seeding trials used an organism from the environment being treated.

[90]R. Colwell, Maryland Biotechnology Institute, University of Maryland, personal communication, February 1991.

[91]U.S. Environmental Protection Agency, Office of Research and Development, bioremediation Action Committee, "Summary of June 20, 1990 Meeting," July 1990.

[92]M.C. Kennicutt, Geochemical and Environmental Research Group, Texas A&M University, personal communication, October 1990.

[93]R.M. Atlas, Department of Biology, University of Louisville, personal Communication February 1991.

a real spill is not the best strategy. The acceptability (or nonacceptability) of bioremediation technologies may take time to establish. The example of dispersant development may provide a relevant analogy for bioremediation in the immediate future: Dispersants have been advocated by many and considered for more widespread use for years, but uncertainty about their effectiveness, as well as continuing environmental concerns and regulatory limitations, has considerably slowed their acceptance in the United States. Probably the most serious setback was the fact that a few early dispersants were toxic; however, since the frost attempts to formulate successful dispersants, toxicity has been addressed and, in some cases, is no longer a serious factor.

bioremediation technologies have been considered for use at sea, on beaches, and in especially sensitive habitats such as salt marshes. It is unclear whether bioremediation could be useful on the open ocean. Most of the scientific community and many oil spill professionals remain skeptical about the utility of bioremediation at sea because rigorously controlled and documented experiments have not yet been done. Several companies have advocated using bioremediation for open ocean spills, but they have not yet produced convincing evidence that their products work as claimed.

In addition to the previously noted problems associated with seeding, a potentially significant problem at sea may be the difficulty of keeping microbes or nutrients in contact with spilled oil long enough to stimulate degradation.[94] This is afar more difficult task than on land or beaches because wind, waves, and currents create a dynamic, changeable environment. As with dispersants, efficient application could also be difficult because ocean conditions are often less than ideal, and the oil may be difficult to locate, may be emulsified or broken into windrows, or in a major spill, may have spread over many square miles. These same problems also limit the effective use of booms and skimmers.

The probability is low that a response with *any type* of technology would be mounted for a spill far out to sea that does not threaten the coast. The initial goal in responding to spills that do threaten the coast is to prevent oil from reaching the shore. Thus, unless seeding, nutrient enrichment, or both can be shown to act quickly *and can be* applied efficiently, spill fighters typically would prefer to get the oil out of the water as quickly as possible or to disperse it. If open sea bioremediation can be shown to be effective over a longer period (i.e., weeks), it might be useful as a response technology either after a full-scale mechanical or dispersant effort had been launched or if such an effort was not possible. Conceivably, nutrients or a seed culture might also be applied to the oil and its residues remaining in the water after the intentional (or unintentional) burning of oil. bioremediation is less likely to be attempted following the use of chemical dispersants; however, there is evidence that some microorganisms may stimulate bioemulsification and thus cause oil to disperse upon application. This possibility and the possible merits and limitations associated with it have not been investigated thoroughly.

Although bioremediation at sea has not been convincingly demonstrated to be effective in *any type* of spill situation, alternative response technologies leave much to be desired. bioremediation, although unproven, appears relatively promising to some. The State of Texas, for example, has been particularly enthusiastic about its potential. Texas has taken the position that there is little to lose by trying it and, given the limitations of other technologies, potentially much to gain or, at least, to learn.[95] The Texas State Water Commission points out that those responsible for responding to an emergency may not be able to wait for a definitive unambiguous ruling from the scientific community on the effectiveness of bioremediation. The Federal Government and other States have been more cautious. The State of Alaska, for example, has tentatively concluded that bioremediation would not be appropriate as an emergency response tool for nearshore spills threatening the coast.[96] In any case, controlled testing, difficult to conduct on the open ocean, will be required to evaluate the potential of bioremediation at sea. ~~bioremediation shows promise for at least some types of open water spills, effective application techniques would still have to be developed for the promise of the technology to be fulfilled.

[94] R.M. Atlas, Department of Biology, University of Louisville, personal communication, Nov. 29, 1990.

[95] B.J. Wynne, Chairman, Texas Water Commission statement at OTA Workshop on bioremediation, Dec. 4, 1990.

[96] E. Piper, Alaska State On-Scene Coordinator, *Exxon Valdez Oil* Spill Response. Letter to Texas Water Commission, Oct. 19, 1990.

Somewhat more is known about the potential for bioremediation of beaches, thanks largely to the Alaska experiments. The potential use of bioremediation methods on at least some beaches looks promising, but, as previously noted, results from the Alaska experiments cannot be extrapolated in toto to other types of beaches or spill situations (especially without more precise knowledge of the effect of environmental and microbiological variables on the rate and extent of biodegradation).

The greater promise of bioremediation for oiled beaches is due in part to the fact that bioremediation is more easily controlled and monitored onshore than it is at sea. Application of nutrients or seed cultures is also easier and less subject to disruption by adverse conditions. Also, once oil reaches a beach, there is usually more time to consider the approach to take: certain damage has already been done, and the emergency response required to deal with oil seeping from a stricken tanker, for example, is no longer quite so necessary.

Depending on circumstances, bioremediation of beaches may be appropriate sometimes as a primary response tool and sometimes as a secondary tool. An important consideration is how heavily oiled a beach is. Heavily oiled beaches may require removal of gross amounts of oil by mechanical means before bioremediation can be a practical finishing tool. Some lightly oiled beaches may not require any treatment. Moderately oiled beaches are likely the main candidates for primary bioremediation treatment. After reviewing the Alaska bioremediation experiments, the Alaska Department of Environmental Conservation concluded that bioremediation was useful as a finishing or polishing tool, but that pooled oil, tar balls, mousse, asphalt, and other heavy concentrations of oil should be picked up with conventional manual and mechanical techniques.[97]

The effectiveness of bioremediation on beaches may also depend on the coarseness of the beach, but the relationship between the size of oiled sediments and the rate of biodegradation has not been evaluated thoroughly. The beaches treated in Alaska with some success were all very coarse, consisting mostly of cobbles and coarse sand. It is uncertain how successful bioremediation of freer grained beaches will be, especially when oil is trapped below the surface. In very fine-grained sediments, lack of oxygen below the surface may limit the rate of biodegradation.

bioremediation, where effective, may offer a promising option for beach cleanup because the existing mechanical technologies can cause additional damage to beaches and beach biota.[98] This damage may be unavoidable if the goal is to "restore" a beach as quickly as possible. Doing nothing (i.e., letting the beach recover naturally at a slower rate) may sometimes be preferable to using mechanical technologies, but this is seldom politically acceptable. bioremediation offers the possibilities of being faster than simply allowing nature to take its course unassisted and of avoiding the negative impacts of mechanical technologies. Moreover, when beaches are inaccessible, the mechanical equipment that can be brought into use may be limited, but fertilizers or seed cultures can be dispensed without the need for massive machinery. In general, bioremediation is less costly and less equipment- and labor-intensive than mechanical cleanup technologies, which suggests a clear advantage for bioremediation where it can be used effectively *instead* of other technologies (e.g., moderately oiled beaches). The advantage is also evident where it can be used as a secondary technology (i.e., as a finishing tool), because it offers the possibility of a more complete solution, more quickly attained (however, the total cost of the cleanup may be greater).

Salt marshes and other sensitive environments, even more than beaches, may be further damaged by intrusive mechanical technologies. For these environments, bioremediation could be the only feasible alternative to doing nothing. Little work has been done in these settings to evaluate the effectiveness or environmental impacts of using bioremediation. Biodegradation of oil stranded in salt marshes is generally limited by oxygen availability. However, the results of one recent study of *waxy crude oils*[99] *in* salt marshes suggest that nutrient enrichment may be an effective countermeasure, provided that large

---

[97]Ibid.

[98]M.S. Foster, J.A. Tarpley, and S.L. Dearn, "To Clean or Not To Clean: The Rationale, Methods, and Consequences of Removing Oil From Temperate Shores," *The Northwest Environmental Journal*, vol. 6, 1990, pp. 105-120.

[99]Waxy crude oils tend to spread, evaporate, and naturally disperse very slowly on water, and usually survive in a relatively fresh state considerably longer than conventional oils.

amounts of oil do not penetrate beneath the aerobic surface layer. Where oil did penetrate the surface layer, the researchers observed little degradation.[100]

Even bioremediation activities, if they are not carefully conducted, have the potential for being intrusive in salt marshes. The scientific support coordinator of the National Oceanic and Atmospheric Administration who monitored the application of microorganisms to Marrow Marsh in the Houston Ship Channel noted, for example, that excessive foot traffic associated with bioremediation operations caused some unnecessary damage to marsh grass.[101]

bioremediation ACTIVITIES IN THE PUBLIC AND PRIVATE SECTORS

The Environmental Protection Agency

EPA is the lead Federal agency for oil spill bioremediation research. Both the Department of Energy and the Department of Defense are actively engaged in research on bioremediation of hazardous waste, but neither these nor other Federal agencies are engaged in research on bioremediation of marine oil spills. EPA regards biotechnologies as having significant potential for the prevention, reduction, and treatment of pollution, and the Agency has placed considerable emphasis on the demonstration and development of these technologies.[102] This coincides with an important general EPA goal of promoting the development of new and innovative technologies to address environmental problems. Agency activities in support of bioremediation for marine oil spills represent a small fraction of its overall biotechnology activities. Nevertheless, EPA would like to establish the technical basis for a national bioremediation response capability for oil spills.[103]

In February 1990, EPA convened a meeting of interested industry, academic, and government personnel "to prepare an agenda for action" for increasing the use of biotechnology. One important outcome of this meeting was the formation of the bioremediation Action Committee (BAC). The objective of the Committee is to facilitate the safe development and use of biotechnology as a solution to environmental problems. The BAC has now been subdivided into six subcommittees: Oil Spill Response, Treatability Protocol Development, Research, Education, Data Identification and Collection, and Pollution Prevention (figure 2). Several of these subcommittees have, in turn, been further subdivided. All subcommittees report to the assistant administrator of EPA's Office of Research and Development (ORD), who functions as the chair of the BAC. Many of the same industry, academic, and governmental representatives who attended the February meeting are participants on the BAC or its subcommittees.

The Oil Spill Response Subcommittee is concerned directly with the bioremediation of marine oil spills. Its major goals are: 1) to evaluate scientific and applied engineering data on the safety and effectiveness of bioremediation technologies; 2) to assess the information required for bioremediation decisionmaking by Federal on-scene coordinators and State oil spill response officials; 3) to prepare interim guidelines on when and how to use bioremediation technologies; and 4) to investigate longer-term issues for incorporating bioremediation into the National Spill Response Plan.[104] An eventual result of deliberations relating to these goals could be the design of a national bioremediation oil spill response plan.[105] However, further research and development of more reliable technologies are required before EPA is likely to undertake the effort required to develop such a plan. In the meantime, the Subcommittee has prepared interim guidelines to assist Regional Response Teams in assessing the desirabil-

[100] K. Lee and E.M. Levy, "Bioremediation: Waxy Crude Oils Stranded on Low-Energy Shorelines," *Proceedings: 1991 Oil Spill Conference, San Diego, CA*, Mar. 4-7, 1991.

101 M-, op. cit., footnote 79.

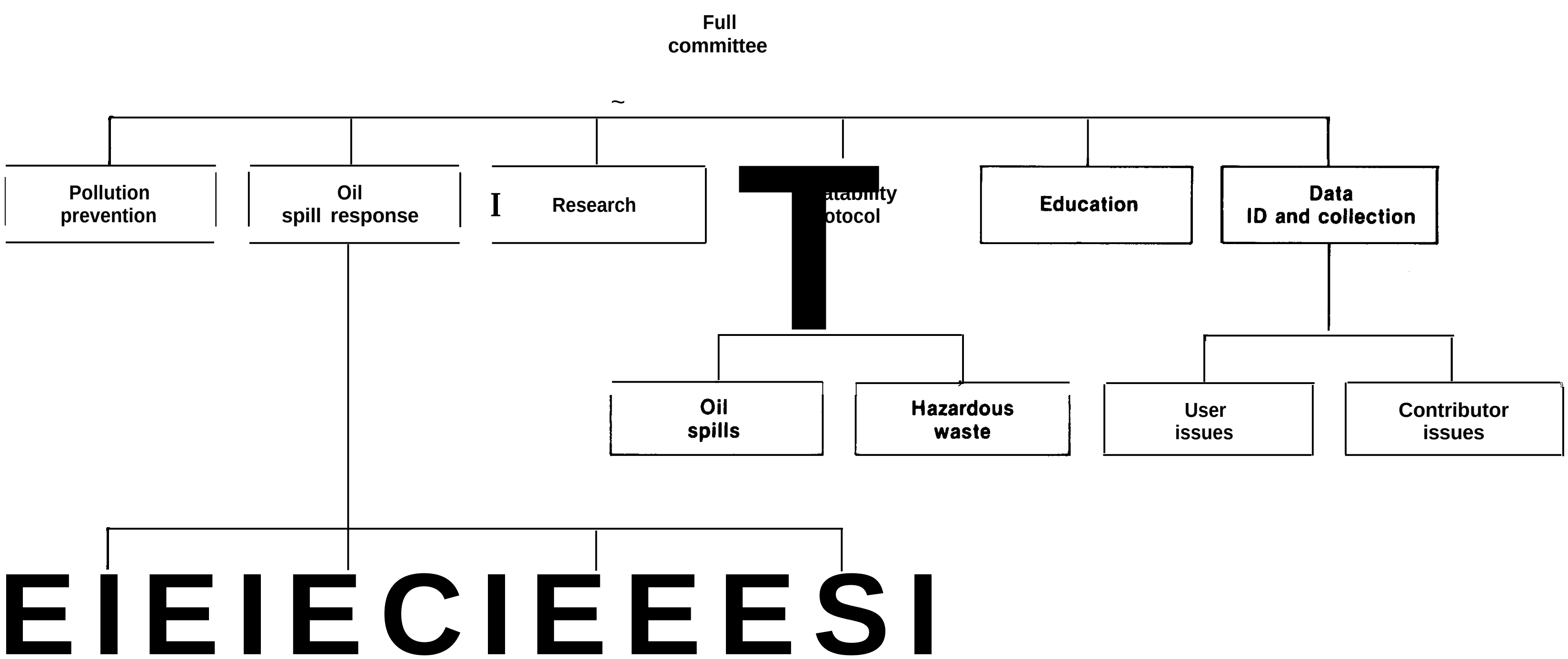
[102] U.S. Environmental Protection Agency, "Summary Report on the EPA-Industry Meeting on Environmental Applications of Biotechnology," Crystal City, VA, Feb. 22, 1990.

[103] U.S. Environmental Protection Agency, bioremediation Action Committee, "Summary of June 20, 1990 Meeting," p. 3.

[104] U.S. Environmental Protection Agency, Office of Research and Development, Bioremediation Action Committee, "Summary of November 7, 1990 Meeting," Washington, DC, Nov. 7, 1990, pp. 4-7.

[105] F.M. Gregorio, member, *Oil* Spill Response Subcommittee, "Development of a National bioremediation Spill Response Plan," Aug. 27, 1990.

Figure 2--Organization of the bioremediation Action Committee



SOURCE: U.S. Environmental Protection Agency.

ity of bioremediation and in planning for its use.[106] Such guidelines will enable decisionmakers to make quick and defensible decisions about the use of bioremediation technologies.

The Treatability Protocol Development Subcommittee has focused its attention on providing technical advice on the development of protocols for testing the applicability and effectiveness of bioremediation technologies in different environmental settings. Protocols use both chemical analyses and bioassays to evaluate a bioremediation product's ability to degrade a waste product or pollutant and to ensure that the product is safe to introduce into the environment.[107] Performance criteria included in the protocols can provide a standard for technology developers against which they can compare their processes.

The development of oil spill protocols is a high-priority EPA activity: without them it is not possible to validate technology or process claims made by product vendors. This activity is being carried out largely through the National Environmental Technology Applications Corp. (NETAC) and EPA's ORD labs (see below). One laboratory-based protocol has already been developed and used to evaluate products intended for use on Alaska's beaches. Work is in progress on the development of an open water protocol, as well as on protocols for sensitive marine environments (e.g., marshes). The Subcommittee will also be involved in developing protocols for bioremediation of hazardous wastes.

The Treatability Protocol Development Subcommittee is also addressing several policy issues related to protocols. For example, bioremediation companies are concerned about having products retested that did not do well initially. Another issue is the recourse available to companies that disagree with test procedures. A third is the means by which results will be reported. (Results will probably be reported as statistically superior to, not statistically different from, or statistically inferior to a standard; products are unlikely to be ranked. Also, products will be judged on different criteria, including efficacy, shelf life, toxicity, etc. A product that does well according to one criterion may not do well on another.) Finally, there is the question of who pays for product testing. EPA appears receptive to some cost sharing with product developers, but only for those products that have met minimum criteria.[108] A cost sharing program involving EPA, the petroleum industry, and product vendors might also be arranged so that a broad commercial testing program could be established.[109]

The main objective of the Research Subcommittee is to identify high priority needs for *general* bioremediation research,[110] not specifically for oil spill applications, but research advances in priority areas could directly or indirectly benefit the latter. The Education Subcommittee will evaluate future needs for scientists, technicians, and engineers in bioremediation research and applications, as well as ways to educate the public about the use of biotechnologies.

Although considerable bioremediation information has been generated by industry, States, and Federal agencies, this information is not necessarily easily accessible, nor has it been certified or standardized for easy use by others. The Data Identification and Collection Subcommittee will focus its efforts on identifying data on field applications and tests of bioremediation technologies (including marine spill applications such as those in Alaska and Texas), on providing guidance for making data available without compromising client or proprietary information, and on establishing routine procedures for submission of data. The Subcommittee has recommended that EPA's Alternative Treatment Technology Information Center (ATTIC) database be used as the central database for all biological treatment technologies. Designed primarily as a retrieval network for information on innovative technologies for treating hazardous wastes, ATTIC should have no trouble incorporating

[106] U.S. Environmental Protection Agency, Subcommittee on National bioremediation Spill Response, bioremediation Action Committee, "Interim Guidelines for Preparing bioremediation Spill Response Plans" (draft), Feb. 11, 1991.

[107] E.B. Berkey, National Environmental Technology Applications Corp., "Presentation of the Progress of the Treatability Protocol Development Subcommittee," Washington, DC, Nov. 7, 1990.

[108] Remarks of J. Skinner, Deputy Assistant Administrator of the Office of Research and Development, U.S. Environmental Protection Agency, during Nov. 7, 1990 meeting of the bioremediation Action Committee.

[109] S. Lingle, Deputy Director, Office of Environmental Engineering and Technology Demonstration, U.S. Environmental Protection Agency, personal communication Feb. 20, 1991.

[110] U.S. Environment Protection Agency, op. cit., footnote 103.

data on the applications of bioremediation for marine oil spills.[111]

The Pollution Prevention Subcommittee is the newest BAC committee. Its purpose is to provide advice to EPA on the potential of biotechnologies for preventing pollution. An example of a pollution prevention application for biotechnology already in use is the treatment of oily ballast water from ships in onshore biological treatment facilities before releasing it to the ocean. This practice is followed, for instance, in Prince William Sound.

A number of EPA laboratories have contributed to the Agency's bioremediation research effort. Prominent among these are the Environmental Research Laboratory in Gulf Breeze, Florida; the Risk Reduction Engineering Laboratory in Cincinnati, Ohio; the Environmental Research Laboratory in Athens, Georgia; and the Environmental Monitoring Systems Laboratory in Las Vegas, Nevada. Table 4 indicates some key bioremediation research needs.

Prior to the ***Exxon Valdez oil*** spill, EPA had virtually no money for oil spill research. Shortly after the March 1989 spill, EPA and Exxon signed a cooperative research and development agreement and initiated the Alaskan Oil Spill bioremediation Project (described above). During 1989, EPA redirected about $1.6 million to the project and Exxon contributed about $3 million. In 1990, Congress appropriated $1 million to EPA for oil spill research, which was applied entirely to the continuing Alaskan project. As in 1989, Exxon contributed about twice as much. To date, about $8 million has been devoted to the Alaskan project, and 1991 will probably be its last year.

Congress appropriated $4 million to EPA for oil spill research activities for fiscal year 1991. EPA expects to spend roughly $2 million of this, not including salaries, for bioremediation research. Beginning in 1992, the Oil Pollution Act of 1990 authorizes a maximum of approximately $21 million annually for oil pollution research and development. The exact amount must be approved by Congress each year, and much less could be appropriated. EPA has asked for $3.5 million of funds available through OPA for fiscal year 1992, a sizable proportion of which will likely be devoted to bioremediation research.

Table 4-Key Research Needs

- **Better understanding of environmental parameters governing the rate and extent of biodegradation in different environments**
- **Improving methods for enhancing the growth and activity of petroleum degrading bacteria**
- **Development of better analytical techniques for measuring and monitoring effectiveness**
- **Field validation of laboratory work**
- **Investigation of what can be done to degrade the more recalcitrant components of petroleum, e.g., asphaltenes**
- **Improving knowledge of the microbiology of communities of microorganisms involved in biodegradation**
- **Better understanding of the genetics of regulation of biodegradation**

SOURCE: Office of Technology Assessment, 1991.

NETAC and Commercialization of Innovative Technologies

EPA has entrusted some of the work of developing new bioremediation protocols to the National Environmental Technology Applications Corp. NETAC is a nonprofit corporation established in 1988 through a cooperative agreement between EPA and the University of Pittsburgh Trust. It was created to help commercialize innovative environmental technologies such as bioremediation.

The *Exxon Valdez* spill provided the opportunity for NETAC to become involved in evaluating bioremediation technologies. After the spill, EPA and the Coast Guard received a number of proposals from companies that wanted their bioremediation products to be tried in Alaska; however, no mechanism existed to enable them to compare competing technologies.[112] One of NETAC'S first charges, therefore, was to recommend criteria by which bioremediation products for cleaning up the Alaska spill could be judged, that is, to develop a protocol for assessing the effectiveness of beach bioremediation products. NETAC convened a panel of experts for this task; from this panel's recommendations, EPA established an official procedure to judge products for possible use in Alaska.

To encourage the submission of products that might qualify for field testing in Alaska in 1990, EPA published an announcement in the *Commerce*

[111] U.S. Environmental Protection Agency, Office of Environmental Engineering and Technology Demonstration, "Alternative Treatment Technology Information Center" (brochure), June 1990.

[112] J.M. Cogen, "Bioremediation Technology for Spilla," *Waste Business Western*, September 1990, p. 17.

Business Daily.[113] *Thirty-nine* proposals were submitted. The NETAC panel evaluated these and recommended that 11 undergo laboratory testing specified by the protocol. Effectiveness and toxicity tests were conducted in EPA's Cincinnati, Ohio Risk Reduction Engineering Laboratory. EPA, again with NETAC's help, selected two products judged most appropriate for field testing in Alaska.

The process of identifying promising products appears to OTA to be both appropriate and fair and, in general, NETAC is performing a valuable service. Nonetheless, a few of the bioremediation firms that had submitted products contended that the tests specified in the protocol were not appropriate to assess the true effectiveness of these products. As more bioremediation research results become available, it will be possible to refine this frost protocol, if necessary. A NETAC expert panel is currently identifying the kinds of studies and types of tests needed for an open water bioremediation protocol, and EPA's ORD labs will again use the resulting framework protocol to develop a complete experimental design. Although much skepticism remains about the effectiveness of bioremediation at sea, an open water protocol would be useful whether or not any effective products were identified.

Relative to the new Interim Guidelines published by the Oil Spill Response Subcommittee, NETAC is also preparing to assist Regional Response Teams in planning for the possible use of bioremediation technologies. Specifically, NETAC has begun to: 1) systematically compile information on commercial bioremediation products, 2) collect samples for preliminary laboratory evaluation of bioremediation products, 3) define a national bioremediation product evaluation facility to test commercial products, and 4) develop the capability to provide technical assistance to the States and to regional or national response teams.[114]

The Private Sector

The bioremediation industry is a young industry seeking to develop markets for its products and expertise. The industry is composed primarily of companies with fewer than 100 employees, and not many of these companies have been in existence for more than 5 years. Of the companies that have developed bioremediation products, few specialize in products for marine oil spills. If a market for such products were to develop, however, many companies would be interested. More than 50 companies Claiming bioremediation expertise have expressed interest in supplying products or personnel in response to the Persian Gulf oil spill.[115] Only a handful of these products have undergone testing to evaluate their effectiveness on marine spills (see above), and none has yet developed a reputation among experts as an effective response to such spills.

The Applied Biotreatment Association (ABTA) was established in 1989 to promote the interests of the bioremediation industry. The organization has 55 members and consists of about equal numbers of corporate and adjunct associates. Corporate members are biotreatrnent companies, and adjunct members include State biotechnology centers, equipment companies, and university professors. In addition to bioremediation companies, ABTA now includes among its members two large oil companies. ABTA recently produced a briefing paper on the role of bioremediation in oil spills.[116] Several of its members actively participate in EPA's bioremediation Action Committee.

For the most part, the oil industry has taken a wait-and-see attitude toward bioremediation. Few companies are doing research on the bioremediation of marine oil spills, preferring instead to let EPA take the lead. Recently, the Petroleum Environmental Research Forum (PERF), an oil industry group that sponsors research on environmental problems of concern to its members, proposed a mass balance study to evaluate the potential of nutrient enrichment and seeding on open water.[117] This study is expected to begin in mid-1991. Although both the American Petroleum Institute and the new Marine Spill Response Corp. believe that

[113] U.S. Environmental Protection Agency, "EPA Seeks Biological Methods for Potential Application to Cleanup of Alaskan Oil Spill,' Commerce *Business Daily,* Feb. 12, 1990.

[114] National Environmental Technology Applications Corp., "NETAC'S Role in Supporting bioremediation Product Selection for Oil Spills," Feb. 11, 1991,

[115] K. Devine, Applied Biotreatment Association telephone Communication Jan. 28, 1991.

[116] Applied Biotreatment Association, "The Role of bioremediation of Oil Spills," fall 1990.

[117] J. Salanitro, Shell Development Co., personal communication Jan. 29, 1991.