application for the National Oceanic and Atmospheric Administration (NOAA) indicated that treated oil changed color within a few minutes to a few hours after treatment, but that after several days there were no significant visual differences between treated and untreated plots. More importantly, chemical analyses indicated "no apparent chemical differences in petroleum hydrocarbon patterns between treated and untreated plots several days after treatment. '[79] Not all of the monitoring data have been analyzed yet, so a final determination of effectiveness has not been made.

Seed cultures may be most appropriate for situations in which native organisms are either present as slow growers or unable to degrade a particular hydrocarbon. Especially difficult-to-degrade petroleum components, such as polynuclear aromatic hydrocarbons, might be appropriate candidates for seeding.[80] In other cases, if a time advantage can be realized, there may be some utility in seeding with a culture consisting of indigenous organisms.[81] Thus, the potential environmental adaptation problems of nonindigenous organisms might be avoided. In many cases, fertilizers would also have to be "added.

Seeding may offer promise in environments where conditions can be more or less controlled. In such cases one would have to consider the proper choice of bacteria, a suitable method of application, and suitable site engineering. Arrangements would have to be made for keeping cells moist and in contact with the oil; for protecting them from excess ultraviolet light; for providing adequate nutrients; and for controlling temperature, pH, and salinity. However, before claims about the utility of seeding marine oil spills can be proved (or disproved), additional research-verified by repeatable experiments—is required.

Seeding With Genetically Engineered Microorganisms

Although it was not demonstrably superior to indigenous organisms and has never been tested in the field, the frost organism ever patented was a microorganism genetically engineered to degrade oil.[82] The rationale for creating such organisms is that they might possibly be designed either to be more efficient than naturally occurring species or to have the ability to degrade fractions of petroleum not degradable by naturally occurring species. To be effective, such microorganisms would have to overcome all of the problems related to seeding a spill with nonindigenous microbes.

EPA has not yet conducted any GEM product reviews for commercial applications, although at least two companies are considering using genetically engineered products for remediating hazardous waste. Since the development and use of GEMs are still limited by scientific, economic, regulatory, and public perception obstacles, the imminent use of bioengineered microorganisms for environmental cleanup is unlikely. Lack of a strong research infrastructure, the predominance of small companies in the bioremediation field, lack of data sharing, and regulatory hurdles are all barriers to the commercial use of genetically engineered organisms.[83] The development of GEMs for application to marine oil spills does not have high priority. Many individuals, including EPA officials, believe that we are so far away from realizing the potential of naturally occurring microorganisms to degrade marine oil spills that the increased problems associated with GEMs render them unnecessary at this time.[84]

ENVIRONMENTAL AND HEALTH ISSUES

To date, no significant environmental or health problems have been associated with the testing or application of bioremediation technologies to ma-

[79]A.J. Mearns, Leader, BioAssessment Team, National Oceanic and Atmospheric Administration, "Observations of An Oil Spill bioremediation Activity in Galveston Bay, Texas,'' March, 1991.

[80]Atlas, "bioremediation of Fossil Fuel Contaminated Sites," op. cit., footnote 67.

[81]R. Colwell, OTA bioremediation Workshop, Dec. 4, 1990.

[82]See, for example, D.A. Friello, J.R. Mylroie, and J.M. Chakrabarty, ''Use of Genetically Engineered Multiplasmid Microorganisms for Rapid Degradation of Fuel Hydrocarbons,"*Biodeterioration of Materials, No. 3, 1976,* pp. 205-214.

[83]U.S. Congress, Office of Technology Assessment, *Biotechnology in a Global Economy* (Washington, DC: U.S. Government Printing Office, scheduled for publication sumner 1991).

[84]A.W. Lindsey, Director, Office of Environment Engineering and Technology, U.S. Environment@ Protection Agency, personal communication, September 1990.

rine oil spills. Experience with bioremediation in marine settings is still limited, so it is premature to conclude that its use will always be safe or that possible risks will be acceptable in all of the circumstances in which bioremediation might be employed. The evidence to date, nevertheless, suggests that risks will be unimportant in most situations.

Concerns have been raised about ***several potential*** adverse environmental effects. Among these are the possibility that the addition of fertilizers could cause eutrophication, leading to algal blooms and oxygen depletion; that components of some fertilizers could be toxic to sensitive marine species or harmful to human health; that the introduction of nonnative microorganisms could be pathogenic to some indigenous species; that the use of bioremediation technologies could upset ecological balances; and that some intermediate products of bioremediation could be harmful.

The possible adverse effects of nutrient enrichment were examined in some detail during the 1989-90 Alaska beach bioremediation experiments.[85] To determine the potential for eutrophication in Prince William Sound, researchers measured ammonia, phosphate, chlorophyll, bacterial numbers, and primary productivity in the water column directly offshore of fertilizer-treated beaches and in control areas. They could find no significant difference between measurements in control areas and those in experimental areas.[86] There were no indications that fertilizer application stimulated algal blooms.

The possible toxicity of fertilizer components was examined in both laboratory and field tests on a number of marine species, including sticklebacks fish, Pacific herring, silver salmon, mussels, oysters, shrimp, and mysids. In the absence of tidal dilution, certain components of the oleophilic fertilizer were mildly toxic to oyster larvae, the most sensitive marine species.[87] However, in the view of researchers working in Alaska, such effects were transient and limited to areas immediately adjacent to fertilized shorelines.[88] The concentration of ammonia, the only component of fertilizers shown to be acutely toxic to marine animals, never reached toxic levels.

Photo credit: Exxon Corp.

Wildlife deterrent device used to keep animals off Alaska beaches sprayed with oleophilic fertilizer. Such devices were used during the short period after application in which the butoxyethanol component of the fertilizer could be harmful to animals coming into contact with it.

The butoxyethanol constituent of the oleophilic fertilizer is potentially harmful to some mammals. This constituent, however, evaporated from beach surfaces in less than 24 hours, during which time wildlife deterrent devices were employed. Care had to be taken, as well, by humans applying the oleophilic fertilizer to avoid inhalation or skin contact. Researchers were also able to show that the oil itself did not wash off the treated beaches and

[85] See, for example, U.S. Environmental Protection Agency, Office of Research and Development *Interim Report: Oil Spill bioremediation Project*, Feb. 28, 1990; R.C. Prince, J.R. Clark, and J.E. Lindstrom, *bioremediation Monitoring Program*, December 1990; and P.H. Pritchard and C.F. Costa, "EPA Alaska Oil Spill bioremediation Project,'' *Environmental Science and Technology*, March 1991.

[86] Ibid.

[87] U.S. Environmental Protection Agency, "Alaskan Oil bioremediation Project: Update," EPA/600/13-89/073, July 1990, p. 11.

[88] Prince et al., op. cit., footnote 85, p. 72.