BIOREMEDIATION: STATUS AND PROSPECTS FOR HAZARDOUS WASTE CLEANUP

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ABSTRACT

The purpose of this paper is to determine the present state of bioremediation technology, as it is used and funded by federal agencies and private sector stakeholders, and to assess the prospects for the future development of bioremediation as a method to clean up contaminated soil and water. To further this aim, technology profiles and progress reports published by three federal agencies, DOE, DOD and EPA, were examined and the dominant bioremediation practices within these agencies were identified. The literature on bioremediation was reviewed to gain insight into the state of bioremediation and its future directions. During November and December of 1991 four people involved in demonstrations of bioremediation at federal facilities were interviewed. From these sources, a picture of the status of bioremediation technology at federal facilities was developed, and its future prospects were evaluated.

INTRODUCTION

Bacteria and other microorganisms have had a long tradition of utility in society. For millennia, humans have relied on the ability of bacteria and fungi to break down garbage and waste. This ability has saved the earth from being covered with fallen trees, animal hair and dead insects as well as the garbage that humans produce. Now, society is faced with the problem of cleaning up dozens of more complex substances such as polychlorinated biphenyls, creosote and naphthalene. The traditional methods for taking care of such contaminants and waste have been to burn, bury or isolate them. These methods, while sometimes effective, also have disadvantages, either because they do not eliminate the wastes or because they may create new problems by generating different wastes.

Public awareness of old waste disposal methods and practices, brought to light by revelations at Love Canal, Times Beach and other sites, has led to public outcry and concern about such practices, which in turn has led to the creation of two major pieces of legislation, The Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Restoration, Compensation and Liability Act (CERCLA). Both CERCLA and RCRA create mechanisms for the financing of hazardous waste site cleanup. However, the technologies used for cleanup are often less sophisticated or powerful than the technologies used to identify the problems. In order to find more effective ways to clean up the large number of hazardous waste sites and the multitude of different wastes, several federal agencies and private developers have been turning to biodegradation as a means to break down and remove contaminants. The use of bacteria and other degradative organisms to clean up waste is termed bioremediation.

Federal agencies, particularly the Department of Energy (DOE), the Environmental Protection Agency (EPA) and the Department of Defense (DOD) have been working on development of bioremediation methods. DOD and DOE have contamination problems caused by a long history of ineffective disposal practices as well as routine leaks and spills from everyday activity. Waste from weapons production, fire training, refueling, mechanical maintenance, painting and cleaning have produced an enormous amount of material that cannot be readily disposed of or destroyed. The EPA, which is mandated to regulate hazardous waste cleanup, seeks effective, low-cost methods to facilitate the implementation of the Superfund program. These three agencies have been conducting research into different methods, including bioremediation, for hazardous waste treatment which may prove to be more efficient or less expensive then traditional methods such as incineration.

Commercial companies have been involved in the development of marketable bioremediation technology which can be applied to private sector Superfund sites as well as to the cleanup of DOE and DOD sites. EPA, through Superfund, has spent two to three billion dollars annually to clean up a small fraction of Superfund sites (1), while the DOD spent over two billion dollars between 1984 and 1989 on its Environmental Restoration Program (2). Commercial developers have worked with federal agencies on cleanup technology development and demonstration.

OVERVIEW OF BIOREMEDIATION

In situ treatment is the simplest of the three types of bioremediation, accelerating the natural process at the site of contamination by addition of nutrients which help the bacteria to grow. Land treatment is like in situ treatment except that there is more control over the soil environment and soil is usually moved or aerated in some fashion. This allows more specific targeting of wastes with particular treatment options. The quickest but most expensive type involves the use of a bioreactor -- a vessel or series of vessels which contains bacteria, nutrients and a mixing mechanism. Bioreactors can attain a nearly optimum treatment environment because they are enclosed systems and can thus be well controlled. However there are high initial capital costs and long-term maintenance costs to consider. These three basic options can be suited to a particular site, and in the case of in situ and land

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treatment techniques, it is important to characterize the site and develop a site-specific plan.

Bioremediation is considered by many to be a low-cost alternative to other remediation technologies (3). Additionally, the potential for bioremediation to eliminate contaminants effectively, resulting in low residual waste levels, is attractive. According to Fox, the types of wastes which have the greatest potential for biological treatment are polycyclic aromatic hydrocarbons, phenols, chlorobenzoic acids, pentachlorophenols, creosote, chlorinated biphenyls (PCBs) and trichloroethylene (TCE) (3).

While nonchlorinated organic compounds are relatively simple to degrade, the current pioneering work is in degradation of chlorinated compounds. Halogenated compounds tend to be highly toxic. PCBs, methyl chloride and carbon tetrachloride are all known to have harmful health effects, as do other, less well known halogenated compounds. Unfortunately, since chlorination usually makes a molecule more stable and less volatile, these toxic compounds tend to persist in the environment. It is important that the environmental fate of these persistent compounds in soil and groundwater be understood and that safe and effective means for degrading or destroying them are found.

One cutting-edge method of enhancing the capabilities of bacteria is to alter their genetic code. The use of genetic engineering in developing strains of bacteria which are capable of TCE degradation is underway and some experts believe that such use will become more prevalent as time goes on (3). The future of genetically engineered microbes in bioremediation, however, hinges on government policy which is still being developed.

One of the biggest questions about bioremediation is whether in situ projects have the effectiveness that is claimed. Proving that lower levels of contaminants are a direct result of biological activity is not always easy. Contaminant levels in groundwater, which many in situ projects treat, can decrease for a variety of reasons, including volatilization, transport and soil adsorption. If bioremediation is to become an important part of hazardous waste cleanup, there must be field confirmation of laboratory results (4).

SUMMARY AND ANALYSIS OF BIOREMEDIATION PROJECTS OF FEDERAL AGENCIES

Two reports have been used to obtain a representative sample of federal bioremediation projects for analysis (5,6). The five agencies represented are the Air Force, Army, Navy, DOE and EPA. The twenty-five bioremediation projects reviewed, eighteen from the Superfund Innovative Technology (SITE) Program (7) and seven done independently by DOD, were categorized by 1) contaminant and 2) type of treatment. The type of contaminant involved varies among the different *projects*, from fuels and oils (e.g., JP4) to explosive and solvents (e.g., HDX, TCE), showing the wide range of possible targets for bioremediation.

The Air Force projects studied were all designed to work in situ. The treatments developed were mostly for the cleanup of petroleum hydrocarbons, including fuel and fuel oil, which indicates that Air Force problems may center around spills of fuel or oil resulting from routine maintenance and refueling near hangars and runways. This sort of site when operational is unsuitable for large-scale oil removal because of the need for continuing use of the site; simple, in situ methods seem to be best suited to the needs of the Air Force.

The Army Corps of Engineers appears to favor either soil excavation followed by treatment in a bioreactor or land treatment techniques. One method modifies simple composting to construct a composting platform. One land treatment process is for removing motor oil from soil, an application similar to the Air Force projects, but the method used by the Army involves disking of the soil as well as addition of nutrients. The Army projects seem to stress removal and isolation of the contaminated media and replacement after remediation. The focus on soil removal and construction may be "cultural"; the Army and particularly the Corps of Engineers are accustomed to large-scale engineering projects, and these forms of bioremediation fit the mold.

The Navy programs are, interestingly, mostly for soil remediation and not for marine cleanup. The emphasis is on fuel and oil spills, similar to the Air Force program. The Navy appears to be the most active branch of the DOD in bioremediation, but the assumption is drawn from limited data. The technology used in the Navy projects vary, entailing nutrient addition, bacterial introduction, vacuum extraction and bioreactor use.

The two Department of Energy projects, TCE cleanup at Savannah River and Organics at Hanford, are both concerned with water -- either wastewater or groundwater. One technology can be used on soil while the other deals strictly with wastewater. It appears that groundwater contamination and wastewater treatment are of the greatest concern to DOE, which has concentrated its bioremediation efforts in that area. Neither technology is designed for in situ use, but instead appears to be variations of either "pump and treat" technologies or waste stream reactors which clean up process wastes before discharge into the environment.

The EPA technologies seem to be designed for general use on a variety of contaminants. Two of the processes are presented as general methods for removing anything biodegradable, with only the general process technology being described. The EPA projects show the widest variety of methods; no particular method is stressed, but the use of bioreactors seems to be favored.

Many of these projects begun in the late 1980s have been completed and some more recent technology development has surpassed their performance. For more detailed information see the report by Kinnel (8).

It appears that, for the most part, the DOD agencies and DOE still continue to work towards solving problems particular to their needs. The largest effort towards cooperation and sharing of information comes from the EPA, though DOE and DOD appear to be willing participants.

INTERVIEWS WITH BIOREMEDIATION USERS

In order to ascertain how bioremediation is being used, contacts listed in "The Superfund *Innovative Technology* Program: Technology Profiles" report (9) were interviewed. Four telephone interviews were carried out in December of 1991 with two EPA employees, one DOE contractor doing research and a civilian employee of the Navy Civil Engineering Laboratory, a soil microbiologist.

When the interviewees were asked what level of contaminant reduction had been achieved, the numbers given were generally higher than those in the Technology Profiles report. All respondents cited cleanup levels of 95% or better as an initial figure, but the interviewees qualified the performance numbers by saying that they were for optimal conditions. The respondents also noted that contaminant levels below 100 ppm could be achieved, which is an important benchmark because it is a regulatory limit for groundwater and soil for many contaminants. One researcher noted the correlation between molecular size and the treatability of the contaminant. Larger hydrocarbons are more difficult to clean up using bioremediation, making it more useful as one in a suite of treatment choices as opposed to a stand-alone process.

Bioremediation performance was compared to other treatment methods, including chemical treatment, solidification and incineration; the latter is the performance leader and the usual standard for comparison. The Two EPA employees indicated that bioremediation is a slower method but it gives similar results to incineration at a lower cost. When questioned about their confidence that degradation was due to biological action, the interviewees all responded positively. The respondents were confident that destruction of the target contaminants was due to biological action.

Three of the interviewees were asked about the costs of their projects. The costs are of three types: one for wastewater, one for soil and one for project development, and as follows:

- \$2.43 to \$3.45 per 1000 gallons of wastewater, depending on the rate of treatment. The technology is used to remove organic contaminants from water.
- \$10 to \$50 per cubic yard of soil with an average of \$12-15/yd^3. This technology is used to remove non-halogenated hydrocarbons from soil and groundwater.
- The development cost of the project for the in situ version was \$5 million and for the above ground version was \$750,000. This technology is designed to treat wastewater and groundwater, removing organic contaminants.

When asked how these costs compared to other methods, incineration was quoted at \$300-\$400 per cubic yard of soil. No comparison was given for a per gallon unit cost, while development costs were only said to be "comparable".

The interviewees were asked to describe the role of their agency in the development of bioremediation. EPA was described as looking for methods to destroy waste and increase safety of storage and landfills, preferably by destroying contaminants rather than storing them. EPA seeks involvement in site demonstrations. DOE was described as divided; basic research is done by the Office of Energy Research, while applied research is done by the Office of Technology Development. The Navy at first worked on bioremediation to treat Navy-specific wastes, but there were too many of these so research was curbed to prevent overlap with other agencies. Other branches of DOD perform a variety of bioremediation research. One interviewee indicated that the Air Force does both basic and applied research, the Army focuses on large-scale projects and the Navy is in between, cleaning up sites and doing basic research as an adjunct to site cleanup.

The interviewees were asked how much involvement there was with other agencies. Interagency work seems common, often initiated by EPA. The interaction was characterized by two interviewees as in planning and oversight of projects, not in development of technology. DOD has good contacts with EPA. The relationship seems to follow a pattern of EPA doing basic research and planning for demonstration, while DOD and DOE do more applied studies, with private contractors also doing some applied work. According to the DOD interviewee, before this type of cooperation was in place, the USAF did most of the bioremediation work in government. One interviewee said that DOE has most of the money so researchers in other agencies are drawn to them for funding and cooperation. DOD has a lot of interactions with other agencies through the Navy Civil Engineering Laboratory (NCEL). EPA is more "available" to other agencies for cooperation than DOD or DOE, but interagency contact is generally "pretty good".

When asked whether the present level of information exchange was adequate, the interviewee from DOE said that one year ago the answer to the question would have been no, but now a significant effort is being made. However, this was countered by a response from DOD which said effort is needed to locate information, while people who are not aware of information make the decisions. Information can also get misinterpreted as recounted by an interviewee: the Navy had been influenced to cut its applied research program as a result of a newspaper story which said that bioremediation is often inadequate to clean groundwater to drinking standards. While this may true, it is often not the goal of a bioremediation project to clean to such a standard.

As a final question, each interviewee was asked whether bioremediation was effective and whether it had a future as a waste treatment technology. "Absolutely" was the reply of one interviewee. Another saw bioremediation as having its niche in treatment options because of its cost and the ability to do work in situ, allowing cleanup to take place without disrupting normal operations at a location. A third respondent said that bioremediation is more important than realized in the past; in wastewater treatment, the best treatment is biological, and other uses are being found for the diverse abilities of natural products. Down the road, bioremediation will expand to more use for organics as well as inorganics using fixation methods which trap contaminants for later removal.

BIOREMEDIATION EVALUATION

Cost

Table I shows that the technologies which have the closest costs to bioremediation are stabilization and vacuum extraction (5). However, neither of these latter two technologies eliminates waste, which bioremediation does. Vacuum extraction can remove volatile chemicals from soil, but the resulting vapor contains chemicals which need further treatment. Stabilization converts soil or sludge into a cement-like substance, which stabilizes contaminants but does not eliminate them. The technologies which destroy waste, such as incineration and chemical detoxification, tend to be more expensive than bioremediation.

If popular perception of bioremediation becomes negative, then the costs are likely to grow due to more stringent regulation and testing. However, it appears that bioremediation technology may be more acceptable than technologies such as incineration, keeping externalities from "not in my back yard" problems from interfering and raising costs. Conventional wisdom is that "[y]ou're getting a lot more favorable publicity if you bioremediate...than if you bring in an incinerator and incinerate the dirt" (10).

Performance

In Table II, performance numbers for bioremediation and selected alternatives are given for comparison (5,6). It is evident from Table I that bioremediation is generally cheaper than other technologies, but Table II shows that performance, as measured by percent destruction, is somewhat poorer.

NPL Sites Using or Considering Bioremediation

Bioremediation has been examined or selected as a remedy in several site cleanups. It is being used as a method to clean up soils or sludges and as a treatment for groundwater contamination. Descriptions of fifteen sites on the National Priorities List (NPL) were examined (11). At nine of these sites, EPA had selected bioremediation as the remedy. At two other sites bioremediation was being used under EPA supervision. Three sites were using bioremediation under state supervision. EPA had proposed bioremediation and was awaiting public comment for one site. Bioremediation has been used at some of these sites as part of a full-scale cleanup.

One common feature of these sites was that they were contaminated with volatile organic compounds (VOCs) and most were also contaminated with polycyclic aromatic hydrocarbons (PAHs). Bioremediation is most effective against these contaminant types. Fourteen of the fifteen sites are evaluating bioremediation for soil treatment, and five of fifteen are evaluating it for surface or groundwater treatment. Only one site had begun treatment with bioremediation as of March 1991; the rest of the sites were doing treatability studies or pilot tests on bioremediation, or were considering bioremediation as one treatment option pending further study.

Sites Potentially Remediable by Bioremediation

Annual summaries of removal actions performed by EPA contain lists of sites, with the primary contaminants occurring at the sites. Some of these contaminants can be treated with bioremediation and others cannot. The hazardous materials found at these sites are grouped into fifteen categories by EPA, as shown in Table III. To estimate the potential for bioremediation use, the contaminant categories were compared to the contaminants treated in pilot projects, demonstrations and technology evaluations (5,6,9). If a contaminant had been treated successfully in these projects, then the category was given a "yes" for status. If laboratory work had shown some progress in treating the contaminant, then it is listed as "in laboratory." If no evidence of bioremediation use was found in the source reports for a contaminant category, then the contaminant is given a "no" in the status column. This is not to say that these contaminants cannot be treated with bioremediation, but that no evidence has been found in the examined reports.

Of 351 sites examined, 247 of them, or approximately 70%, had at least one primary contaminant that had potential to be cleaned up using bioremediation. This calculation does not take into account individual site characteristics which may lower the percentage. Yet even if half of the potential sites

TABLE I
Cost of Remediation Technologies

Bioremediation	
Biological Treatment for Groundwater Remediation	$6.3 million for development $0.0165/gal of wastewater
In Situ Biodegradation	$100-200/ton of soil $230-300/gal. fuel spilled
Biodecontamination of Fuel Oil Spills	$37,000 for 800 m^2 of soil
On Site Fuel Oil Remediation	Aerobic: $ 50/yd^3 of soil Anaerobic: "should be less"
Unsaturated Zone in Situ Bioreclamation	$ 50/yd^3 of soil
Vacuum Extraction/ Bioremediation	$80/ton in pilot project
Incineration	$200-400/yd^3.of soil
Thermal Destruction	• oxygen or propane fuel:$3000 • Burner: $150,000 • Design: $50,000
Stabilization	$30-200/ton of soil
French Drain	• Investigation:$500,000 • Engineering: $75,000 • Construction: $1.5 million
Vapor Recovery	$70,000-100,000 total cost
Vacuum Extraction	$50/ton of soil
Solvent Extraction	$150-450/ton of soil
Chemical Detoxification	$250/ton of soil

TABLE II
Performance of Remediation Technologies

Bioremediation	
Above Ground Treatment of Trichloroethylene	80% destruction of TCE
Biodegradation of Lube Oil Contaminated Soils	aerobic: 60% removal of waste oil
Composting of Explosives Contaminated Soils	99% reduction of contaminant at 55°C
In Situ Bioventing	50% destruction in 7 months 80% destruction at optimum conditions
Biodegradation: TCE in Soil and Ground Water	using propane, 99% efficient using methane, 50% efficient
U1/U2 Ground-Water Biological Treatment Demonstration: Nitrates and Organics in Ground Water and Wastewater	>99% NOx destroyed 93% CCl_4 destroyed
Biotreatment Enhanced with Pact®/Wet Air Oxidation: Organic Contaminants in Wastewater	removal of contaminant to below detection (ppb range)
Biological Aqueous Treatment System: Organic Compounds in Ground Water and Process Water	as high as 97% removal of contaminant
Rotary Air Stripping	>99% removal of volatiles
Solvent Extraction	>99% (90-98% in field) removal of contaminant
Ultrox	90% removal of total VOCs
In situ soil venting	80% of material spilled
Incineration	>99% destruction possible
Infrared Thermal Destruction	>99.99% destruction of contaminant
Rotary Kiln	99.9999% destruction of contaminant

TABLE III
Contaminants as Candidates for Bioremediation

Contaminant Category	Status
Arsenic	no
Dioxins/Furans	no
PCBs	yes
Asbestos	no
Cyanide	no
Non-volatile Organics	yes
Pesticides	in laboratory
Waste Oil	yes
Toxic gases	no
Metals	in laboratory
Acids	no
Bases	no
Solvents	yes
Inorganic Waste	no
Radioactive Waste	no

yes = has been demonstrated in field
no = has not been demonstrated
in laboratory = research is ongoing

were discarded as unsuitable, approximately one third of hazardous waste sites could still be treated using bioremediation.

Bioremediation Research Needs

The Bioremediation Action Committee (BAC) was formed by EPA to further the development of bioremediation technologies to solve environmental problems. On April 15 and 16, 1991, a workshop sponsored by the BAC identified four areas in which bioremediation research is required to meet both short and long-term needs: 1) make pollutants more accessible to bacteria, 2) improve process design; 3) work out scale-up problems; and 4) develop new processes (12).

CONCLUSIONS

Bioremediation has been referred to as a cleanup technology which is almost ideal because it can completely degrade waste, it can work at the site, it has a reasonable cost and it is relatively free of harmful effects (13). Federal agencies are taking interest in bioremediation for just those reasons. However, the effectiveness and suitability of bioremediation in the field is not accepted by everyone. The Bioremediation Action Committee has named some of the problems associated with bioremediation in their workshop report (12). Because the agencies doing bioremediation research have used diverse research methods and technologies, there has not been a focused approach towards solving the problems that bioremediation presents. DOE and DOD seem to do bioremediation research based on need; they concentrate on developing technologies which are specific to their problems. EPA takes a different approach, developing technologies to have broad applicability for many types of hazardous waste problems. These objectives to some extent complement one another.

Current bioremediation research is showing that a wider field of contaminants can be treated than previously believed. Chlorinated compounds, including PCBs and some pesticides, can be degraded biologically. Some recent research has shown that metals can be accumulated in organisms and extracted later, which could be useful for removing contaminants from soil and water. A wider field of treatable substances makes bioremediation suitable for a large number of site cleanups, and if bioremediation's promise as an inexpensive technology is realized, it has the potential to lower cleanup costs for many sites.

As new technologies and design improvements are made, the performance of bioremediation is improving. Performance figures for older bioremediation approaches are generally lower than those for more recently developed techniques. Interviewees quoted removal percentages greater than 95% under optimal conditions for certain bioremediation technologies. The project undertaken by the Marine Corps at Camp Pendleton has shown removal of contaminants to below detection limits (8). Even if bioremediation does not achieve such levels of contaminant destruction, it can be used as an initial step to remove 80-90% of a contaminant inexpensively, while the remaining contaminant can be treated with other technologies.

The costs of bioremediation have been shown to be less than for other destructive technologies (6). The cost savings projected by the Marine Corps from the Camp Pendleton project are over one hundred million dollars for one site. The potential cost savings if bioremediation is used at large numbers of sites is significant, as long as the technology remains low-cost in a large-scale project.

Bioremediation is not a highly specialized technology. It can be done by any size company, from a small independent venture to a huge multinational corporation. Companies which are demonstrating bioremediation technologies have total sales for all activities which range from over ten billion to around ten million dollars. Many companies may end up using bioremediation to clean up their own sites, so it may be worthwhile for larger companies to develop bioremediation technologies on their own, as Allied-Signal has done. As biological processes and biotechnology become more widely used, bioremediation could be a starting point for companies interested in moving towards biological technologies. Particular interest in bioremediation is shown by the petroleum industry to clean up leaking underground storage tanks (10).

EPA has recognized bioremediation as an acceptable remediation technology for site cleanup. It has been selected as the remedy for several NPL sites, and has garnered support from EPA in the form of the Biosystems Initiative. Former EPA Administrator William Reilly has been vocal about EPA's support of bioremediation. However, although prospects for bioremediation are bright, finding examples of full-scale bioremediation projects is difficult; most of the projects which have been done are pilot projects and demonstrations.

It is difficult to get specific expenditures for bioremediation research from DOE and DOD. General expenditures for environmental cleanup are available, but specific numbers regarding bioremediation were not readily available. More detailed funding information is needed in order to provide a basis for determining if bioremediation support is adequate and if it is being effectively utilized. Adjustments to research spending and integration of research efforts would be possible if more detailed accounting was available.

If bioremediation is used more often, awareness will increase and public perception will become an important consideration. The level of awareness of bioremediation appears to be low, despite high profile use in the Exxon Valdez oil spill cleanup. The differentiation among different methods of bioremediation may become important as public awareness increases. The concerns about in situ treatment with indigenous organisms should not be as great as those for treatment of waste with engineered organisms.

RECOMMENDATIONS

Research on Bioremediation

Given the potential of bioremediation, expanded research activity seems worth supporting. In addition to the agenda set forth by the BAC Workshop, the research agenda should include the following: 1) Research into novel uses of biodegradation and microbial metabolism. Using fungi or bacteria to extract metals or using biodegradation on vapor phase material are feasible and demonstrable processes. Further investigation of the broad tastes of bacteria might yield unusual degradative abilities, especially if bacteria work sequentially to degrade a contaminant (syntropy), or degrade chemicals unintentionally through metabolic pathways designed for other compounds (cometabolism); 2) Research on environmental and human health effects of bioremediation. Though bioremediation should have little impact because it is a naturally occurring process, the use of nutrient addition may disrupt the soil system and the addition of organisms could disrupt the balance of microflora in the soil. The possible effects of using bioaugmentation and genetic engineering should be studied as well, so that they can be used if safe, or discarded if the risks are unacceptable; 3) Research into public acceptance of bioremediation should be undertaken and a balanced educational program should be started to inform people about the benefits and drawbacks of bioremediation. Bioremediation is theoretically a low risk technology; however, public perception of bioremediation is still uncertain and information is scarce. Should bioremediation becomes a technology of choice, then information about public attitudes will be very important.

Collaboration and Information

Further effort among federal agencies to collaborate on projects would be helpful to the development of bioremediation. Collaborative efforts should also be coordinated so that performance and cost accounting is more uniform among projects, allowing easier comparison of bioremediation to other technologies. The present system of data acquisition and dispersal needs to be improved. Many companies, military bases and government agencies have access to wide area computer networks such as the Internet which, if used, would be one way to improve the sharing of data. Information retrieval would be faster and more convenient for both government and private organizations, provided that the quality of data was monitored through a review process.

CLOSING REMARKS

Bioremediation has a great deal of potential, and if care is taken in the development of the technology and support of research, then this potential could very well be realized. Bioremediation will remain an important choice for site remediation as one of many innovative technologies. Federal agencies, which must enforce and comply with the regulations that require the cleanup of hazardous waste, should work together to get bioremediation out into the field more quickly. Hopefully, the lower costs and improving performance of bioremediation will help businesses and taxpayers save money, while reducing risks by destroying hazardous wastes.

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