JSR-95-330

JASON

MITRE

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Washington, D.C. 20585

Dear Ari:

During the past summer, we had the opportunity to examine aspects of the remediation program of the Department of Energy (DOE). The most important conclusion that we have come to is that there is an urgent need to mount a comprehensive research program in remediation. It is also clear to us that your office does not have the funding to carry out a program on the scale that is required. On the other hand, Environmental Management could very well fund such activities. We would hope that in the future there would be close collaboration between Environmental Management and Energy Research in putting together a comprehensive and well thought-out research program.

We will comment below on one aspect of remediation: subsurface bioremediation. As you know, last summer we undertook a detailed look at some of the problems involved in such bioremediation. This summer, we considered mainly certain programmatic aspects.

In general terms, possibilities for environmental restoration of polluted DOE sites may be put in the following categories, singly or in combination:

1. Removal of the pollutants to "acceptable" repositories;
2. Sequestration, i.e., immobilization and burial of the pollutants on the site;
3. Massive dilution for pollutants that cannot be adequately immobilized —to a degree that renders the concentrations acceptably small whenever the pollutants spread into sensitive areas;
4. Chemical, biological or other conversion of harmful pollutants into benign substances.

As noted above, we reviewed only possibilities for the biological conversion of harmful pollutants.

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In the following, we focus on those hazardous wastes that are already dispersed in the ground, whether through leakage from above-ground tanks, careless past waste disposal practice, or deliberate underground burial. At many sites, the pollutants have already spread well beyond the original burial areas. Where the contamination is still sufficiently localized, as around certain tanks, it might be possible to construct underground barriers against further spreading. This is difficult enough. In situations where the pollution is spread over wide areas, the problem of restoration becomes truly awesome. Conceptually, the surest restoration method is to dig up all the affected ground in order to wash or dilute pollutants. However, it is estimated that the cleanup of polluted DOE sites by proven dig-and-wash operations would cost upward of a trillion dollars and take many decades of work. The prospect is sufficiently grim to mandate that intensive effort be devoted to research on alternative methods. Bioremediation—the use of micro-organisms as miniature chemical factories for in-situ processing—seems to be the least unpromising of the alternatives for dealing with large volumes of polluted ground. In some cases, it is only the metabolic product of the microorganism that must be carried to the pollutant, e.g., microbially produced surfactants that act on oil sludges.

Any bioremediation therapy would involve the following steps, in order of increasing difficulty:

1. Monitoring the extent and motion of the subsurface pollutants;
2. Finding and engineering appropriate micro-organisms that can act on the pollutant substances to render them benign;
3. Transporting the microbes or their precursors (which might conceivably be merely genetic instructions) in sufficient numbers to the polluted site that they can carry out the wanted remediation.

Our understanding of how living, dividing cells work has grown enormously in the four decades since the structure and dynamics of DNA were first successfully described. There has been a corresponding explosion of advances in the engineering and cloning of these chemical micro-factories. The pace is so great that one cannot foresee with confidence the achievements that will be accomplished in the next two decades. Protocols already exist for coaxing a bacterial population—through partial starvation, special nutrients and ambient genetic material—to produce, after many generations, a subpopulation that might metabolize certain predesignated organic molecules that the initial population ignored. These methods have not been based as yet on sequential engineering from known blueprints. It is not unreasonable to hope for success in the future with goal-oriented engineering of bacteria that could metabolize a specific organic molecule in an in-situ environment similar to that which harbors a subsurface pollutant. Bacteria that ingest certain heavy metals are already known to exist. If nature has achieved robust and varied subsurface microbial life (as it has), key parts of this can probably be stimulated and altered in the laboratory. For the purposes of remediation, the goals of such research would be the discovery and/or engineering of various survivable, multiplying bacterial species that could metabolize potential carcinogens, ingest heavy metals, and defang chemicals that are toxic to animal and plant life.

Work on genetic engineering of microorganisms is expanding on a worldwide scale, quite apart from its potential for environmental remediation. The knowledge base relevant to that application is therefore likely to grow. The problem of subsurface transport of bacteria (or of precursors that can serve to transform certain ambient bacterial populations into remediators; or of bacteria after they have ingested quantities of heavy metals) has received far less attention.

Based on these considerations, we believe priorities can be set for research in bioremediation. Because substantial developments in microbiology and bioengineering will proceed independently of DOE investment in these areas, many findings and techniques relevant to bioremediation are likely to arise without direct DOE investment. However, there are so many different families of microorganisms and so wide a range of interest in them that avenues of research important to bioremediation of the kind needed at DOE sites may well be underemphasized. We believe, therefore, that DOE should have its own substantial and direct involvement in a vigorous program of goal-oriented research aimed at:

1. The identification and bioengineering of "useful bacteria";
2. Increasing our understanding of how to transport those bacteria (or their precursors) to the subsurface sites of pollution;
3. Experimental investigations directed toward the evaluation of promising techniques for in-situ remediation.

We would rank the priorities for a dedicated DOE bioremediation program in the following order:

1. Goal-oriented research concentrated in areas associated with remediation that are not being pursued sufficiently outside the DOE program (e.g., focus on bioengineering of microorganisms directly relevant to bioremediation and subsurface bacterial transport);
2. Relevant remediation-related research which, because of special talent and/or equipment, can be performed significantly better at the DOE facility than elsewhere.

3. More wide-ranging, basic research in the biotechnology areas for which DOE's talent and equipment provide promising opportunities for significant advances.
4. Fundamental research in areas of universal interest, such as the origin and evolution of existing biological systems at great depth.

In the present financial climate, a new federally supported microbiology laboratory, even if successful and eminent, would probably be vulnerable. To survive and succeed, it will be important that the DOE laboratory be well focused and pre-eminent in the pursuit of bioremediation techniques rather than having a broader charter to pursue fundamental knowledge that might or might not have some bearing on the remediation mission in the very long term. The Environmental and Molecular Sciences Laboratory of DOE could, as we have written to you earlier, become more focused on the bioremediation task. It has to be said that a narrower focus on bioremediation by talented microbiologists for whom fundamental knowledge is probably a more attractive goal will require special leadership. The order of priorities that we proposed for the bioremediation laboratory would present difficulties whose resolution would require strong and tactful leadership at the top. From the broad perspectives of microbiology, the laboratory will be seen by some to be rather narrowly focused--on the search for special classes of bacteria for special applications that may involve transport not common in nature. However, a concentrated focus on crucial short-term objectives can be stimulating and attractive, as demonstrated by the Manhattan and Apollo Projects; but, even optimistically, bioremediation is going to be a protracted effort. As with even the longer-term fusion effort, the bioremediation program will have to achieve a balance between focus on the central mission—environmental remediation—and tolerance of inner-directed scientific sorties into broader domains. The problem of balance is, of course faced by all mission-oriented laboratories. It is especially stark here, however, because at this stage and for the early future the line to be followed is not all that clear. Not just labor, but good ideas are needed. The laboratory has to be able to attract good minds to focus on a critical mission that is not much on the agenda of pre-eminent laboratories elsewhere. This calls for especially sensitive, wise, and energetic leadership.

In conclusion, a large, well-supported DOE microbiology laboratory will presumably have certain large-scale equipment not readily available elsewhere. This would be an attraction for the outside community, as well as the in-house scientists. There could be considerable interest in making the equipment available for some fraction of the time as an outside "user" facility. In sister disciplines, this has proven to be beneficial for the laboratory as well as for the outside users, bringing in, as it does, a flow of talented visitors and collaborators.

It would be wise to explore ways in which such a use of exception equipment could similarly be exploited within the microbiology community.

We hope that you may find these views with respect to a bioremediation program useful for future planning.

Sincerely yours,

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Gordon J. MacDonald
Malvin A. Ruderman
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