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OFFICE OF
THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

EPA-SAB-EEC-92-026

Honorable William K. Reilly
Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, D.C. 20460

Subject: Science Advisory Board Report on Review of ORD's
Draft "Bioremediation Research Program Strategy"

Dear Mr. Reilly:

The Science Advisory Board (SAB) has completed its review of the Office of Research and Development's (ORD) "Bioremediation Research Program Strategy" (December 1991 Draft) and is pleased to submit this report. On February 10 and 11, 1992, the Bioremediation Research Review Subcommittee (BRRS) of the SAB's Environmental Engineering Committee reviewed the draft document, received extensive briefings from research managers and scientists who developed the document, debated technical arguments, and offered advice to ORD on this promising remediation technology.

Our findings and recommendations are aimed at improving the current Bioremediation Research Program Strategy document (hereafter referred to as the Strategy Document). We are pleased to see the broad Agency and inter-laboratory participation in this research planning effort, which led to the development of a comprehensive document that clearly contains the considered thoughts of a talented group of scientists and engineers. We draw your attention and look forward to a response in particular on the following highlighted findings and recommendations:

- 1) The BRRS found that the strategy presented in the draft document, which is interactively driven by actual assessment of site conditions and knowledge gaps, to be useful and basically sound in concept and commend the Agency on the team approach used to address the topic. This site-directed approach is fundamental to development of all bioremediation strategies and will help determine whether any generic approaches are feasible.

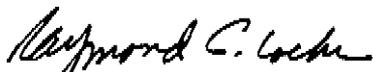
- 2) The BRRS stressed that, while the strategy has many good features, the draft document and the entire bioremediation research program could benefit greatly from a more explicit treatment of the strategic planning process. To be specific, the Strategy Document should be more sharply focused and integrated by employment of a rigorous strategic planning process. A clear vision statement of EPA's role in bioremediation, combined with critical assessment of the state-of-the-science and technology, would lead to a more defined concept of the research program needed to further the Agency's mission in this important field. The Administrator may wish to provide such guidance to others in the Agency for development of their strategic plans.
- 3) A sharpened focus for the program should lead to development of better mechanisms of program outreach, inter-agency coordination, and leveraging to maximize the benefits of EPA's resources in the bioremediation field. The EPA bioremediation strategy needs to recognize other EPA research, as well as have an "open windows policy" to reach out to and keep abreast of new developments in the field. In particular, there is a need to coordinate with other governmental agencies, as well as with the private sector regarding the critical engineering aspects of bioremediation.
- 4) The Strategy Document should include information which pays attention to the current regulatory framework in which the technology must be used and applied. Regulatory roadblocks can preclude bioremediation as a technology of choice, and need some attention in the document. This information would be helpful both to the Agency and the regulated community.
- 5) The Strategy Document should include greater attention and progressive effort to meet the needs of the user community --- those that apply bioremediation for environmental cleanup.
- 6) Bioavailability is a major factor limiting wide-scale application of bioremediation technologies. There is a need to conduct research to understand the physical-chemical changes that affect bioavailability of chemical pollutants including mixtures, in order to develop more effective bioremediation technologies.
- 7) A clearer identification of waste types as to contained chemicals will improve the understanding of the Strategy Document and how the actions relate to

existing problems. It is exposure to the chemicals in the wastes that cause the adverse effect to human health and the environment.

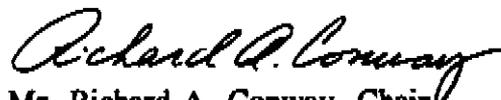
- 8) Budget information is included in the Strategy Document, but the BRRS believes that funding available is inadequate to support effective implementations of the proposed Bioremediation Research Program Strategy. It is therefore essential for EPA to pursue both Agency-wide and government-wide planning and coordination in this important area of bioremediation research and technology development.
- 9) Concepts related to performance evaluation of an on-going bioremediation field project should be expanded; and toxicity issues associated with bioremediation should be focused on real-world pilot and field situations and not on possible secondary by-products that may not occur or may occur only in special situations or exceptions.
- 10) Specific criteria to measure progress and success of bioremediation research and technology development are needed.

The SAB has offered a series of broad-ranging and specific programmatic recommendations to enhance the quality and usefulness of the Strategic Document. We are pleased to have had this opportunity to be of service to the Agency. We trust that these comments will help in your guidance of this important program and look forward to your response.

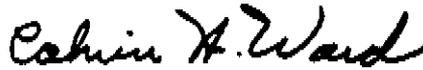
Sincerely,



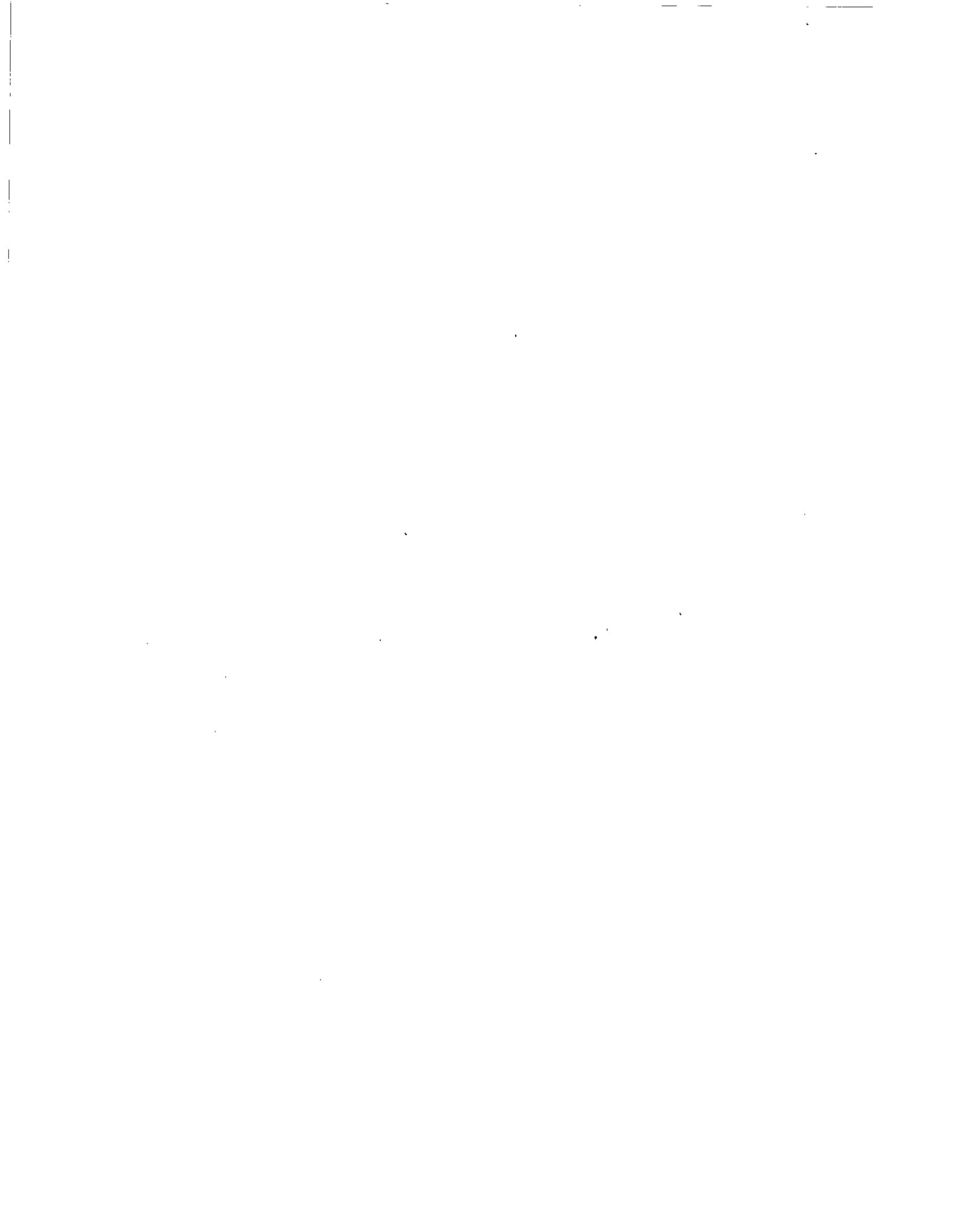
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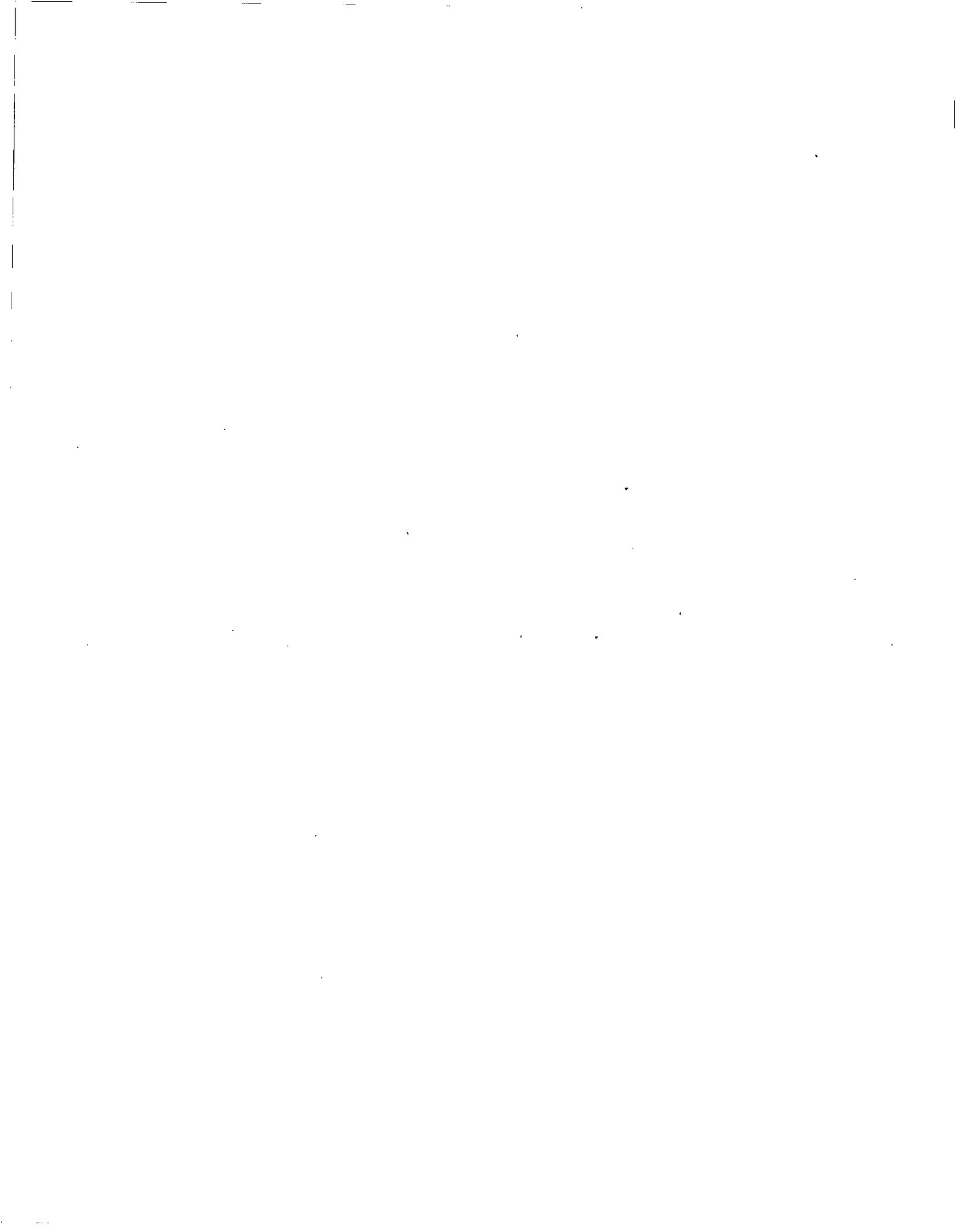
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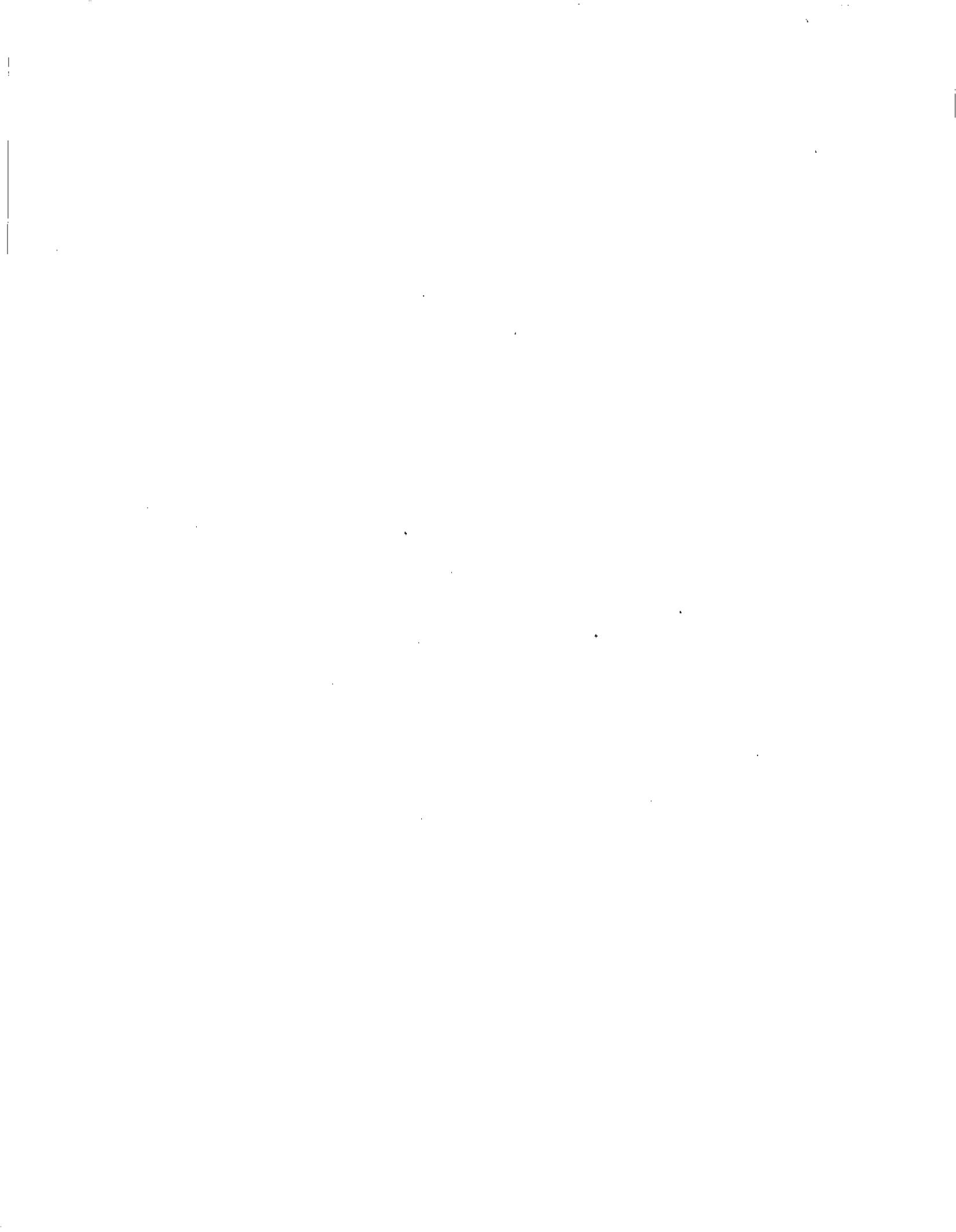
EPA AN SAB REPORT: REVIEW OF BIOREMEDIATION RESEARCH PROGRAM STRATEGY

REVIEW OF THE OFFICE OF RESEARCH AND DEVELOPMENT'S BIOREMEDIATION RESEARCH PROGRAM STRATEGY



NOTICE

This report has been written as a part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide a balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency; hence, the comments of this report do not necessarily represent the views and policies of the Environmental Protection Agency or of other federal agencies. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

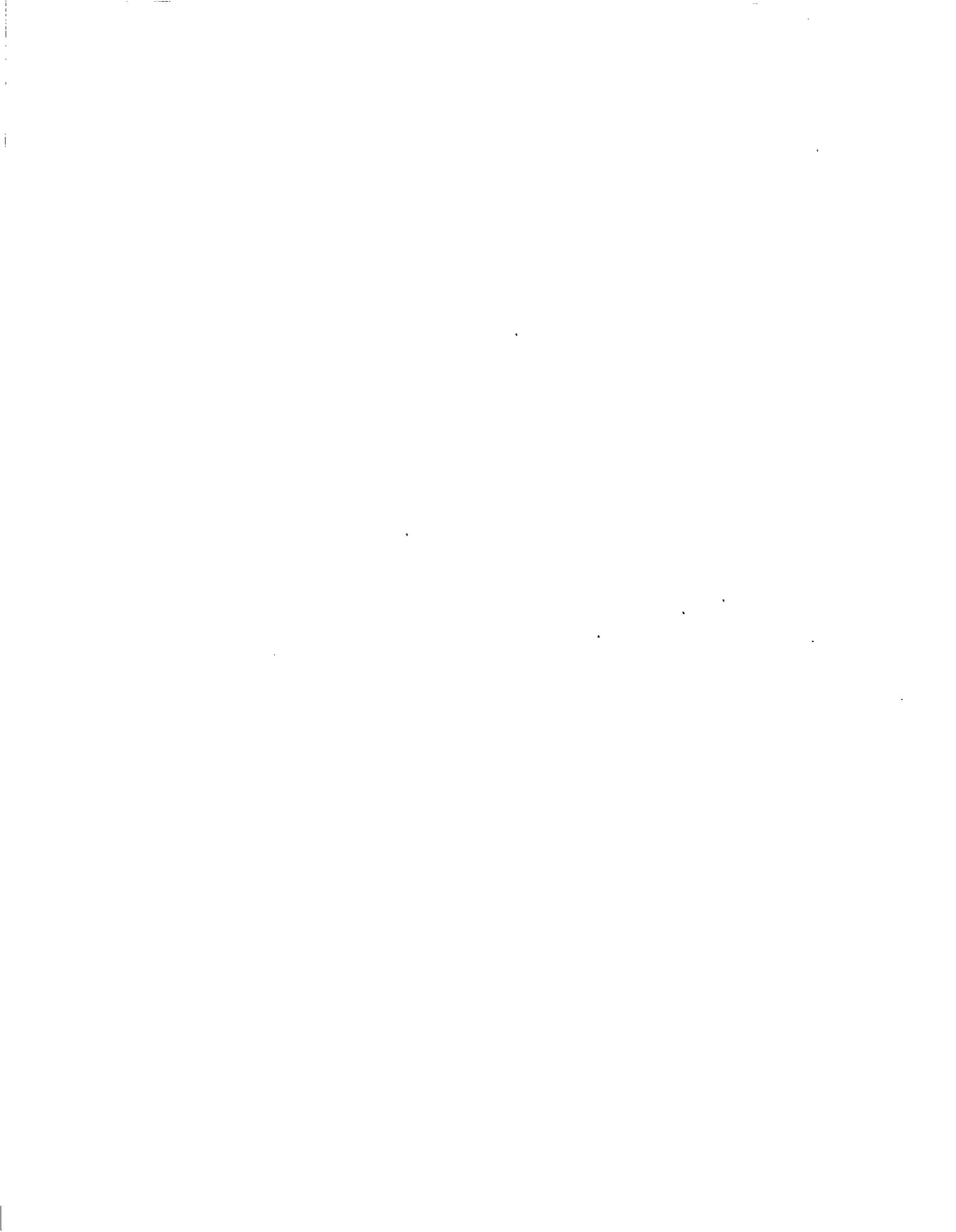


ABSTRACT

The Bioremediation Research Review Subcommittee (BRRS) of the Environmental Engineering Committee (EEC) of the EPA Science Advisory Board (SAB) has reviewed the Office of Research and Development's (ORD's) "Bioremediation Research Program Strategy," December 1991 draft. The BRRS found that the strategy presented in the draft report, which is driven by actual site conditions and knowledge gaps, to be useful and basically sound in concept. The BRRS commends the Agency on the team approach used to address the topic, but recognized that the authors need to clarify concepts and terminology related to the term, "site-directed approach." The BRRS believes that, while the strategy has many good features, the draft document and the entire bioremediation research program could benefit greatly from a more explicit treatment of the strategic planning process.

Additional recommendations are as follows: Bioavailability is a major factor limiting wide-scale application of bioremediation technologies. There is a need to conduct research to understand the physical-chemical changes that affect bioavailability of chemical pollutants including mixtures in order to develop more effective bioremediation technologies; there is a need to coordinate with other governmental agencies, as well as with the private sector; the EPA bioremediation strategy needs to recognize other EPA research, as well as an "open windows policy" to reach out and keep abreast of new developments in the field; and specific criteria to measure success are needed. A number of other recommendations were made with the aim of improving both the draft strategy document and the Agency's overall bioremediation research program.

Key Words: Bioremediation, Bioremediation Research, Bioremediation Research Program Strategy



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1. EXECUTIVE SUMMARY

This report presents the Science Advisory Board's (SAB) review of the Office of Research and Development's (ORD) "Bioremediation Research Program Strategy" (December, 1991 Draft). On February 10 and 11, 1992, the Bioremediation Research Review Subcommittee (BRRS) of the SAB's Environmental Engineering Committee (EEC) reviewed the draft document, received extensive briefings from research managers and scientists who developed the document, debated technical arguments, and offered advice to ORD on this promising remediation technology. Additional review occurred in mail correspondence with the BRRS and the EEC. The EEC conducted public reviews on the various draft reports at the EEC meetings of March 4 and 5, 1992 and July 7 and 8, 1992. Throughout the process, the BRRS offered additional commentary to refine the recommendations contained herein.

Our findings and recommendations are aimed at improving the current Bioremediation Research Program Strategy document (hereafter referred to as the Strategy Document). The following highlights key findings and recommendations:

- 1) The BRRS found that the strategy presented in the draft document, which is driven by actual site conditions and knowledge gaps, to be useful and basically sound in concept and commends the Agency on the team approach used to address the topic.
- 2) The SAB believes that the site-directed approach used to develop the Strategy Document is appropriate and basically sound. However, the BRRS suggests that the authors need to clarify concepts and terminology related to the term, "site-directed approach."
- 3) The BRRS believes that, while the strategy has many good features, the draft document and the entire bioremediation research program could benefit greatly from a more explicit treatment of the strategic planning process.
- 4) A sharpened focus for the program should lead to development of better mechanisms of program outreach, inter-agency coordination, and leveraging to maximize the benefits of EPA's resources in the bioremediation field.
- 5) The Strategy Document should include information which pays attention to the regulatory framework in which the technology must be used and applied. Regulatory roadblocks can preclude bioremediation as a technology of choice,

and need some attention in the document. This information would be helpful both to the Agency and the regulated community.

- 6) The Strategy Document should include greater attention and progressive effort to meet the needs of the user-community --- those that apply bioremediation for environmental cleanup.
- 7) Bioavailability is a major factor limiting wide-scale application of bioremediation technologies. There is a need to conduct research to understand the physical-chemical changes that effect bioavailability of chemical pollutants including mixtures, in order to develop more effective bioremediation technologies.
- 8) The title of the document should be changed to more clearly reflect the nature of the strategy. As now written, there is no clear, succinct statement about the strategy focus.
- 9) Bioremediation opportunities at source generator sites need to be more explicitly recognized in the strategy document.
- 10) A clearer identification of waste types as to contained chemicals will improve the understanding of the Strategy Document and how the actions relate to existing problems. It is exposure to the chemicals in the wastes that cause the adverse effect to human health and the environment. The EPA bioremediation strategy needs to recognize other EPA research, as well as an "open windows policy" to reach out and keep abreast of new developments in the field.
- 11) Budget information is included in the Strategy Document, but the BRRS believes that funding available is inadequate to support effective implementation of the proposed Bioremediation Research Program Strategy. It is therefore essential for EPA to pursue both Agency-wide and government-wide planning and coordination in this important area.
- 12) Concepts related to performance evaluation of an on-going bioremediation field project should be expanded and toxicity issues associated with bioremediation should be focused on real-world pilot and field situations and not on possible secondary by-products that may not occur or may occur only in special situations or exceptions.

- 13) Specific criteria to measure progress and success of bioremediation research and technology development are needed.

A number of other recommendations are made in the report with the aim of improving both the draft document and the Agency's overall bioremediation research program.

2. INTRODUCTION

The Biosystems Technology Development Steering Committee of ORD prepared a draft document entitled "Bioremediation Research Program Strategy," (hereafter referred to as the Strategy Document).¹ The Bioremediation Research Review Subcommittee (BRRS) of the Environmental Engineering Committee (EEC) of the EPA Science Advisory Board (SAB), reviewed the draft Strategy Document, dated December 1991, at a meeting on February 10 and 11, 1992. On those dates, the BRRS also received extensive briefings from research managers and scientists who developed the document, debated technical arguments, and offered informal advice to ORD on this promising remediation technology. The Strategy Document review was attended by many of the Agency's personnel who actually participate in bioremediation research. Additional review occurred by mail correspondence with the BRRS and the EEC. The EEC conducted public reviews on the various draft reports at the EEC meetings of March 4 and 5, 1992 and July 7 and 8, 1992. Throughout the process, the BRRS offered additional commentary to refine the recommendations contained herein.

The BRRS was given a charge which focused on a strategy review, rather than a detailed program review.² The Subcommittee was asked to specifically focus on strategic directions articulated in the draft document. The major questions asked of the BRRS are as follows (Please note that table and figure numbers cited below refer to tables in the Strategy Document):

- 1) Is a site-directed approach appropriate for focusing the Agency's bioremediation research program? Will it adequately address application problems that limit its use in the field?
- 2) Are the waste types and site matrices targeted in the strategy as priority site categories (Table 2) the most appropriate for focusing research efforts?
- 3) Do the major scientific and engineering gaps identified in Table 3 adequately cover the problems associated with applying bioremediation?
- 4) Are the consensus knowledge level rankings identified in Tables 4, 5, and 9 reasonable? Is this an appropriate means of identifying research emphasis

¹ U.S. EPA, Bioremediation Research Program Strategy, prepared by the Biosystems Technology Development Steering Committee, Office of Research and Development, December 1991.

² Memorandum from E. Timothy Oppelt, Director, RREL-Cincinnati, Ohio to K. Jack Kooyoomjian, Designated Federal Official of the SAB/EEC, January 8, 1992.

(i.e., process, pilot, field research, etc.) shown in Table 10 for the priority site categories?

- 5) Will the research framework with its associated feedback mechanism (Figure 2) enable ORD to achieve and refine the program objectives?
- 6) Are the research outputs (Tables 6, 7, 8) adequate to provide guidance to regional Superfund staff, remediation contractors, and the bioremediation industry that will result in the effective and appropriate use of bioremediation in the field? Are there other outputs that would be effective in achieving this goal?, and
- 7) Given the identified budget constraints, do the funding distributions depicted in Figures 3, 4, and 5 provide the proper mix of process and pilot/field research to support both fundamental understanding and engineering development of bioremediation?

The following Subcommittee findings and recommendations deal with the Strategy Document and are aimed at improving it. The findings and recommendations of the BRRS have been distilled from the dialogue which occurred at the February 10 and 11, 1992 meeting, and from subsequent deliberations on the topic by the BRRS and its parent Committee, the EEC. The BRRS has attempted to specifically address the issues and questions posed by ORD and also offers wider-ranging guidance to strengthen and focus the Strategy Document.

This review has been organized into the following sections: 1) Key Findings and Recommendations on the Draft Bioremediation Research Program Strategy, 2) Specific Technical Suggestions on EPA Bioremediation Research, and 3) Comments on Document Presentation.

3. KEY FINDINGS AND RECOMMENDATIONS ON THE DRAFT BIOREMEDIATION RESEARCH PROGRAM STRATEGY

The BRRS is strongly supportive of the Agency's role in bioremediation research and technology development, and believes that the Strategy Document for the program should clearly explain its current status and plans for future directions. The Subcommittee also believes that the Strategy Document should serve to explain the program's objectives, focus, structure, operations, budget requirements and relative place in EPA research and development activities. Hence, key findings and recommendations are directed toward providing guidance to improve and strengthen the programmatic and management value of the document. The key findings and recommendations are as follows:

- 1) A Site-Directed Approach to the Research Strategy Development is Appropriate and Basically Sound in Concept. Based on review of the draft document, as supplemented by verbal explanation, the SAB found the Bioremediation Research Program Strategy, which is driven by actual site conditions and knowledge gaps, to be useful and basically sound in concept. It identifies and focuses on many important issues, has feedback from field findings to basic research as well as feed forward, recognizes the need for various types of technology transfer in and out of the program, and provides seldom-included budget estimates. The EPA personnel who prepared the Strategy Document should be commended. It is a focused summary that allowed it to be reviewed as a strategy rather than a compilation of individual projects. In addition, the material was presented well, thus allowing the Subcommittee to identify the key elements and gaps.
- 2) A Team Approach to the Research Strategy Development is Productive. We commend the Agency on the team approach used to address the topic. The various ORD laboratories obviously worked together to address this Agency-wide program, rather than handle it on an individual laboratory basis. The team approach which has led to this program plan and strategy should be continued and encouraged, and used as a model for other EPA research programs. However, while the bioremediation program plan has benefitted significantly from inter-laboratory participation, the strategic planning process should be strengthened.
- 3) A More Explicit Treatment of the Strategic Planning Process is Needed to Guide EPA Research on Bioremediation. While the strategy has many good features, the draft document and the entire bioremediation research program could benefit greatly from a more explicit treatment of the strategic planning

process. The process should consist of: a) establishing a vision, b) assessing the current state of research, and c) selecting the most appropriate pathway from the present to the vision.

The vision provides a clear, unified direction for the research. As currently formulated, each individual researcher has his or her own vision of where the research effort should go within the bounds of research interests of the individual researcher. Though individual's visions may be worthwhile, they may not be appropriately focused or prioritized for this research effort to be fully successful. Embarking on the strategic planning process is consistent with the SAB's advice^{3,4} and with the Agency's stated strategic direction of "providing leadership in the nation's environmental science, research and assessment efforts."^{5,6} The mission should address the extent to which bioremediation fits into our nation's program with its rather strict goals.

With regard to the current state of bioremediation research, little mention has been given to what has gone before. Bioremediation is not a new concept. Clearly, a sound basis already exists upon which bioremediation advances should be pursued. With the vision and current assessment in place, the most appropriate path can be selected from this logical reference framework. The EEC notes that these issues related to strategic planning and the need for a vision statement have come up before. For all strategic plans, including this one, the Agency should rigorously implement a basic three-step process: a) establish a vision, b) determine the current state of the issue, and c) prepare a plan to achieve the vision.

- 4) Regulatory Constraints Need Attention. The Strategy Document should include information which pays attention to the regulatory framework within which the technology must be used and applied. There are many opportunities in the Strategy Document to show how bioremediation could be used in treating RCRA, CERCLA and UST sites. Technically speaking,

³ U.S. EPA/SAB, Future Risk: Research Strategies for the 1990's, Science Advisory Board, EPA-SAB-EC-88-040, September 1988.

⁴ U.S. EPA/SAB, Reducing Risk: Setting Priorities and Strategies for Environmental Protection, Science Advisory Board, EPA-SAB-EC-90-021, September 1990.

⁵ "EPA...Preserving our Future Today," Strategic Direction for the U.S. Environmental Protection Agency, dated April 1991.

⁶ "EPA...Preserving our Future Today," U.S. Environmental Protection Agency Strategic Plan, Draft IIb, October 17, 1991.

bioremediation may be the most appropriate remedial option for a particular application. If, however, regulatory constraints prevent its application, then the value of the research is greatly lessened. In fact, existing regulations and regulatory agency resistance can preclude bioremediation as a technology of choice. Some attention must be given in the document to identify these regulatory constraints which could limit implementation of the technology. Technical discussions to aid in overcoming these constraints should be included, as well as acknowledgement that information gaps and practical shortcomings of the state-of-the-art currently limit broad applications of bioremediation technology. This would be helpful information for both the Agency and the regulated community. The SAB Executive Committee observed that there are differences in the acceptance of bioremediation in Europe, as compared to the United States context, noting that the regulatory atmosphere in Europe is more conducive to such applications.

- 5) Defining Resource Needs and Timeliness of Outputs. Resource needs and timeliness of outputs should relate to the strategic planning process in the Strategy Document and particularly to question #7 in the charge to the SAB's BRRS (See introduction and reference #2). The resource information in the Strategy Document implies that adequate resource allocation has already been made to carry out the bioremediation research program. However, on examining the needs for research, development and demonstration covered in the Strategy Document and EPA staff responses to questions asked during the SAB's BRRS review, it appears that the adequacy of budget projections should be reevaluated, particularly from the viewpoint of assuring timely delivery of outputs envisioned in the strategy. The Subcommittee finds that the existing budget is too small. It is further suggested that the Agency should focus the Strategy Document on a realistic discussion of what the Agency can expect to achieve with the available resources versus what the Agency actually needs to accomplish with the stated goals and additional resources.

- 6) The Site-Directed Approach Needs Further Clarification and Description. The Subcommittee believes that significant confusion exists in the report about the "Site-Directed Approach" used in the planning process. Within the BRRS, there were several different interpretations of what is meant by the concepts and terminology related to the "Site-Directed Approach." Further, the Subcommittee asks that the Agency clarify and define the meaning of "site generic categories." The authors of the strategy need to clarify whether sites are considered as generic categories, as well as clarify the terminology dealing with environmental compartments, specific field locations, locations where

specific wastes are found, or combinations of the above. What assumptions are being made about common contamination and environmental settings of sites in particular categories? Until this is clarified, it is difficult to fully appreciate and evaluate the appropriateness of this organizational approach for the Bioremediation Research Program Strategy.

- 7) Coordination with Other Governmental Agencies is Needed. The Strategy document gives no indication of any integration of planning with other governmental agencies; (e.g., DOE, DOD, and the individual military branches) and possibly NSF, or initiatives outside of these established organizations in a global perspective. The Subcommittee recognizes that individual EPA scientists and engineers have meaningful contacts with colleagues in other governmental agencies. Nevertheless, these do not represent a substantive coordination in a holistic way, nor does the Strategy Document represent a strategic method for joint planning. The budget for EPA's bioremediation research is small relative to the resources perceived by the Subcommittee as needed. In fact, relative to other Federal agencies, the EPA budget currently and in the future to support bioremediation research is not adequate. It is therefore essential for EPA to pursue both Agency-wide and government-wide planning and coordination in this important area.

EPA should embark on a senior staff level coordination effort with other Federal agencies, rather than rely on individual project level contacts. The establishment of a mechanism for joint government-wide planning would require action by senior personnel in all relevant agencies.

EPA's science-oriented bioremediation program is appropriate for the Agency. But it is critically important that this science-based program be coordinated with the technology-based programs being conducted by other agencies and industry. This is essential, because materials handling, especially contact between contaminants, bacteria, and growth support parameters, is the critical issue. The Agency needs to help build mechanisms for joint planning and coordination within its organization and between Agencies, as well as between government and industry.

EPA is in fact proposing to include: a) identifying developments that are part of the EPA Hazardous Substance Research Centers (HSRCs), b) all-investigator symposia, c) workshops on bioremediation, and d) specific conferences on relevant topics. All of these activities will help, but will fall short of the actual effort needed to fully keep abreast of developments. To

generate significant coordination, EPA needs an "open windows policy" to reach out with the Strategy Document (See Reference # 1, pg. 3) with the goal of keeping abreast of new developments in the field, such as those occurring in the EPA HSRCs.

As described above, there are many exciting and state-of-the-art bioremediation research efforts underway that are not funded by EPA and therefore will not be recognized and integrated by the approaches indicated in the Strategy Document. EPA should undertake an active program to identify such research, to have "open windows" to acquire such information to reach out to joint involvement with such research. Such research is being done in many industry laboratories, (e.g., major petroleum firms), as part of the investigations conducted for other governmental agencies, (e.g., DOD and DOE), by universities (e.g., University of Texas and University of Michigan) and independent contract laboratories, and in other countries.

The recent EPA report, "Safeguarding the Future: Credible Science, Credible Decisions," ⁷ calls for EPA to place its scientific goals and achievements before the public, as well as to draw on the expertise of other organizations to obtain the best scientific information possible. While SAB reviews, such as this, place the Agency's achievements before the public, EPA currently lacks adequate mechanisms for successfully utilizing expertise of other organizations and to acquire such information from the broader scientific and engineering community. A stronger, broader effort is needed than that indicated in the Bioremediation Research Program Strategy document.

Specifically in this research area, EPA should have an active program that reaches out to non-EPA researchers in all organizations and encourages them to share their knowledge. This can include: a) focused efforts to find out who is doing relevant bioremediation research and the objectives of that research; b) specific invitations to such individuals to participate in workshops, symposia, and planning meetings; c) the possibility of joint planning of research so as to take advantage of other efforts and of sharing the results of such research; and d) exploring possibilities of rotational assignments that allow scientists from other organizations to work in EPA science programs and EPA scientists to participate in research at non-EPA locations. This latter

⁷ U.S. EPA, Safeguarding the Future: Credible Science, Credible Decisions, The Report of the Expert Panel on the Role of Science at EPA, EPA-600-9-91-050, March 1992, pages 18-19.

approach on rotational assignments is a specific recommendation of the "Safeguarding the Future" report, and is especially important in the bioremediation area which is clearly an inter-agency effort.

In summary, a positive, active program is needed to reach out and involve efforts of the broad scientific and engineering community involved in bioremediation research. The program identified in the bioremediation Strategy Document is a beginning but an inadequate overall effort.

- 8) Coordination and Involvement with the Private Sector is Encouraged. Much of the knowledge on factors limiting bioremediation, problems with technology implementation, and research and development on bioremediation technology resides in the private sector. Large chemical, petroleum and engineering companies, as well as smaller private firms, have information and knowledge that can be useful to the development and implementation of the EPA bioremediation research strategy. Therefore, a system should be devised to obtain regular advice from scientists and engineers from the private sector on the priorities, approaches and needs for EPA's bioremediation program. This could be implemented in a number of ways, such as with planning workshops, symposia and innovative coordination and support activities. However, the EEC notes that the issue of barriers to technological information transfer, such as proprietary issues, need to be examined. EPA's participation and leadership in the Bioremediation Action Committee is a positive, but only a modest start in the right direction.

- 9) EPA Bioremediation Strategy Needs to Recognize Other Related EPA Research. Biological research within EPA that is relevant to the Biosystems Technology Development Steering Committee's Bioremediation Research Program Strategy, but not currently included in it, should be listed and described in a table or appendix. Expectations from that research and ways by which that research will be accessed (not directed) should be added to the Strategy Document. Programs of particular interest include the oil spill bioremediation research program, research in the UST program which has led to the development of the "LOCI" model, research sponsored by the exploratory research center program, and specific research projects supported by EPA's competitive grants program.

4. SPECIFIC TECHNICAL SUGGESTIONS ON EPA BIOREMEDIATION RESEARCH

Establishment of a clear vision and well defined objectives for the EPA bioremediation research program will provide focus for specific research initiatives and guidance for the Agency's niche in this important area. The Subcommittee review of the draft Strategy Document has lead to a series of specific suggestions which should be considered in the research planning process. The Subcommittee has also attempted to identify specific areas of research which appear to be inadequately emphasized in the draft document.

- 1) Specific Criteria to Measure Success of Bioremediation Projects are Needed. The Subcommittee suggests that the strategy contain explicit criteria to follow progress of bioremediation in the field and to measure success and accomplishment of research outputs. For example, Technical Resource Documents (TRDs) are expected to be clear, concise and easy-to-use products that will enable the intended users to apply them for "real-time" decisions. The Subcommittee suggests that while a TRD is a document which only provides technical guidance and, as such, cannot set up a system to measure success, the TRDs should give clear guidance on ways to measure success and progress of bioremediation field studies. Whenever possible, differentiation should be made between what would have happened naturally, without intervention and how intervention changed the course of bioremediation.
- 2) Concepts Related to Performance Evaluation Should be Expanded. The purpose of bioremediation is to degrade, detoxify and immobilize constituents that may pose a threat to human health and the environment. Thus, it is appropriate that toxicity issues associated with bioremediation be addressed. However, the toxicity research should be focused on real-world possibilities and not on elucidation of secondary by-products that may not occur or may occur only in special situations or exceptions. Rather, an early effort of the proposed bioremediation toxicity research should be investigations of on-going pilot and field scale situations.

Large-scale bioremediation efforts are underway at many locations in the U.S. Samples from these sites could be obtained and the relative toxicity changes monitored and related back to the degradation and changes in chemical constituents. Samples from a few such sites have indicated that the relative toxicity is likely to decrease at the same rate or faster than the loss of specific chemicals. Such a real-world comparison would: a) provide a reality

check for the toxicity generation assumptions being made and b) more closely tie toxicity changes to actual bioremediation process performance. Only if there is clear evidence that there are relative toxicity increases would there be a need to identify possible intermediate by-products, causes for the toxicity increase, and methods to cause the increase not to occur.

To pursue the identified bioremediation toxicity research efforts as described in the Strategy Document may be to evaluate a potential problem which is in reality a non-problem. By tying the toxicity research into actual bioremediation laboratory, pilot and field studies, a reality check will be included and more meaningful performance evaluation data will be obtained.

In a like manner, the immobilization question also should be part of any bioremediation process performance. Information from laboratory and field studies indicates that as bioremediation proceeds, the remaining constituents become less soluble, less available for leaching and therefore less mobile. Thus throughout a bioremediation study, samples should be evaluated for the relative mobility of constituents. This can be done by standardized leaching procedures such as the Toxicity Characteristic Leaching Procedure (TCLP) or others that may be more appropriate.

By relating changes in mobility of constituents to degradation and chemical loss by bioremediation, the overall performance of the bioremediation process can be better evaluated. Judgements on the technical and environmental feasibility of bioremediation will be made on more than just loss of specific chemicals or on degradation rates.

In terms of performance evaluations, it is not clear how the information acquired will be related to design relationships and parameters that feed into ultimate use of bioremediation processes and specifically into the Technical Resource Documents (TRDs). Without this connection, it is possible that very good scientific data will result, but unfortunately will not be able to be included in engineering design. An example would be to provide a link between the microbial characterization data and process performance so that chemical loss rates ultimately can be calculated in terms of mass of chemical lost per unit time per mass of active organisms. Wherever possible, the experiments should be planned to obtain chemical loss rate data and the effects of environmental parameters or management options on such rate data.

- 3) Categorizations of Waste Type Should Reflect the Logic of the Strategy
Categorization of waste type in the Strategy Document is awkward and interferes with a quick understanding of the logic involved. The waste types include chemicals (solvents, halogenated aromatic hydrocarbons or HAHs, and pesticides) and industries (wood preserving and munitions). While these are items common to Superfund sites, it would be better and less confusing if there were more commonality such as using categories that are all chemicals. Thus for wood preserving, the category could be polycyclic aromatic hydrocarbons (PAH) as a chemical class of concern and for munitions waste, it could be metals or specific organics.

The current waste type categorization makes it appear that there are not other major industries causing Superfund or RCRA corrective action problems, whereas there clearly are. For instance the petroleum refining and petrochemical industries contribute waste to both Superfund and RCRA corrective action sites. The BRRS was told that constituents of such industries are understood to be included in the wood preserving category. However, the Strategy Document does not make this clear. Similarly, UST problems include petroleum and petroleum products that are different from the usual solvents, yet apparently are included in the solvent category. A clearer identification of waste types as to contained chemicals will improve the understanding of the Strategy Document and how the actions relate to existing problems. It is exposure to the chemicals in the wastes that cause the adverse effect to human health and the environment.

- 4) The Title of the Strategy Document does not Reflect Content. The title of the Strategy Document should be changed to more clearly reflect the nature of the strategy. In addition, early in the Executive Summary and the Introduction, the primary focus of the strategy should be clearly stated. As now written, there is no clear, succinct statement about the strategy focus. Rather, the focus is scattered throughout several paragraphs.

As stated by EPA personnel in the discussions, the Bioremediation Research Program Strategy is to meet the needs of EPA and other individuals involved in Superfund, RCRA corrective action, and UST remediation and clean-up efforts. A reader of the Strategy Document must go through many paragraphs and sometimes pages before this focus finally sinks in. Someone looking at the title could infer that the Strategy Document addresses much more, such as non-hazardous industrial wastes and even the use of bioremediation for municipal wastewaters, and sludges. Thus, it would be

appropriate to consider a more descriptive title to the document such as, "Hazardous Waste, Superfund and UST Bioremediation Research Strategy" and more clearly define this focus in the opening paragraphs of the Executive Summary and the Introduction.

- 5) The Strategy Document Should Support the Development of Technology Decision Support Systems. Proper application of bioremediation technology at present is an inexact science, even in the hands of the limited number of highly skilled technologists in the field. Other more mature fields of technology have developed Decision Support Systems (DSSs) to aid in the training of new personnel. These DSSs eventually take the form of computer programs into which is placed a synthesis of the accumulated knowledge of those individuals most skilled and experienced in the technology. Timely development of DSSs will enhance the usefulness of the TRDs and promote the most appropriate and cost-effective wide-spread use of bioremediation technology.

The Subcommittee suggests that DSSs, or "simple decision software" be discussed in the Strategy Document as possible products that will increase the value and use of the TRDs. Of course, the term, "simple decision software", needs to be defined. There are pros and cons as to whether such systems are sufficiently developed to support this recommendation. In fact, such systems could serve to limit further development in the field, or at least limit remediation options. Some of the BRRS members and consultants suggested that software is useful when decisions on applications are being done by inexperienced persons or non-experts. In this case, however, decisions should be made by experienced persons where such guidance is less necessary. At a minimum, the Agency might consider a discussion of the pros and cons, as well as a definition, of DSSs or "simple decision software" in the Strategy Document.

- 6) Suggestions for Specific Research Topics to be Included in the Strategy. The authors of the Bioremediation Research Program Strategy are to be commended for preparing a comprehensive list of scientific and engineering knowledge gaps (Table 3). The Subcommittee has identified several additional knowledge gaps

and research areas that should be considered by the Biosystems Technology Development Steering Committee:

- a) There is minimal information on the dynamics of biodegradation of mixed materials containing multiple contaminants, other than petroleum hydrocarbons. The Strategy Document should include research needed to address the nature of stimulatory, inhibitory or complementary interactions that are possible.
- b) No apparent attention has been given to integrated process technologies for waste remediation. These integrated techniques usually involve combinations of physical, chemical and biological processes. There is significant work underway on a variety of potentially useful combinations that need to become part of the bioremediation strategy. A specific example could include surfactant or co-solvent enhanced product recovery from the vadose zone, followed by vacuum extraction for further residuals removal and bioventing for "polishing." Numerous other integrated methodologies are needed for application in a "treatment train" concept.
- c) There is a need to conduct research to understand the physical - chemical changes that affect bioavailability of chemical pollutants and mixtures in order to develop more effective bioremediation technologies. Bioavailability of parent and aged chemical complexes is one of the factors most widely recognized as limiting the efficacy and wide-scale application of bioremediation. Chemical aging (weathering) should be a major thrust of the Strategy Document.
- d) The Strategy Document does not recognize the bioremediation potential at existing source generators, such as landfills, and other land disposal facilities as bioreactors. Clearly, the application of bioremediation to these facilities is not outside the purview of the initiative. In situ bioremediation, while different for landfills and other land disposal facilities is often a reality which would moderate the potential migration and environmental effects of residuals and conversion products from these sources, as well as direct the requirement and extent of possible post-transport relating to external bioremediation decisions and efforts.

5. COMMENTS ON DOCUMENT PRESENTATION

The intent of the Subcommittee's comments on document presentation is to help 1) clarify some of the language and terms used in the draft document, 2) ensure that the needs of the users of bioremediation technology receive appropriate attention, and 3) provide focus to communication and technology transfer activities, such as program symposia and workshops on bioremediation. The following comments are intended to focus on improving presentation within the Strategy Document.

- 1) Greater Consideration of Technology Transfer to the User Community (Process Engineer) is Needed. Success ultimately will be judged by the knowledgeable application of bioremediation. It is critical that the user community (i.e., engineer/remediation managers) be supplied with engineering data and information which will support effective decisions regarding the application of bioremediation. A clearly defined technology transfer activity which provides this required information should be incorporated into the Strategy Document. Additionally, it is suggested that a serious discussion on science versus engineering/technical development needs of the various segments of the user community would be most helpful in the Strategy Document.
- 2) The Process Used in Preparing the Tables of Information Presented in the Strategy Document Should be Explained and Disclosed. To a large extent, the description and direction of the program strategy is based on various types of information contained in tables in the report. These tables appear to have been prepared in a subjective manner on the basis of input provided by various Agency bioremediation experts. It would be very helpful to explain the process used in preparing the tables and how the rankings were established. Additionally, since these tables provide direction, it would be worthwhile to explain who was involved in the ranking process, as well as the backgrounds and affiliations of all participants. This material could be provided in an Appendix or integrated into the text. By disclosing the process more fully, the reader could gain an appreciation for the nature, origin and hence the validity of the process and the information in the tables. The reader can then more appropriately focus on the more substantive issues within the strategy.
- 3) Knowledge Gaps Need Prioritization and Major Gaps Need to be Identified. The major knowledge gaps are identified in the Strategy Document (Table 3), but their significance is diminished by including an extensive listing of factors related to microbiological degradation in general and not to bioremediation of

hazardous waste sites in particular. An example is "environmental conditions (pH, temperature, redox potential, moisture content and organic carbon content)." One approach to address this issue would be to rank items by asterisks in Table 3 or separate out in a second table the major or priority information gaps. In the latter case, Table 3 should be retitled. The Subcommittee is not suggesting that comprehensiveness be abandoned, but cautions against the implication that all items are equally important.

- 4) FY 92/93 Research Program Needs Particular Attention to Performance, Evaluation and Modeling. Performance evaluation and modeling programs need particular attention in the FY 92 and FY 93 research program mix (Tables 12 and 15). For example, sampling would be important in the former and aerobic processes in the latter. The narrative on performance assessment (Section 3.1.5) should focus on generic issues such as sampling and surrogates. Such work is on-going within EPA and needs to be included in the document.
- 5) Tables Need Clarification. A subgrouping should be added to indicate projects by waste categories in Tables 12, 13 and 15 to clarify the presentation.
- 6) Symposia and Workshops Need More Thought Toward Intended Objectives. It is uncertain whether the state-of-the-science and technology symposia and workshops have clearly stated objectives and will contribute to specific research initiatives, or to broader generic issues. Symposia and workshops should support the timely delivery of technology resource documents and aid in the effective implementation of bioremediation processes (Tables 6 and 7). The impending symposium on reductive dechlorination should be exemplary of a more specific thrust, however, as officially entitled as "Anaerobic Processes," the symposium may be too broad to contribute directly to any work product of the bioremediation research program. Additionally, the symposia and workshops should be focused to provide inputs to the development of DSSs for technology application and implementation.
- 7) Consistency of Terminology Needs Greater Attention. When reviewing the document, special care should be given to the consistent use and application of terms. The following specific suggestions deal with terminology:
 - a) In the draft Strategy Document, there is a question regarding the use and application of terms such as "site", "treatment", and "in situ" as applied to technologies. For example, since the term "site" may have

several meanings, there may be potential for confusion if this term is not used in a consistent manner.

- b) The term "treatment" is used in the text to describe the level of biodegradation achieved in experimental studies. Because this term has a defined meaning with in the context of CERCLA, RCRA and UST activities, its use in a generic sense to convey biodegradation, rather than achieving a required level of restoration, could be misconstrued.
 - c) In situ is used throughout the document to describe a variety of technologies, some of which meet the strict definition of in situ, which suggests a process that is non-intrusive and non-disturbing. Other usages may reflect hybrid technologies which combine in situ and ex situ elements. Furthermore, the preferred spelling of in situ (i.e., in situ) should be checked throughout the document.
 - d) There is inconsistency regarding the use of and different meanings of HAH (Halogenated Aromatic Hydrocarbons) and H & AH in the document. It would seem that the term, H&AH, is synonymous with HAH. These terms should be defined, or one of them dropped.
 - e) Solvent(s) is (are) inappropriately used in the document to include both chlorinated solvents and petroleum hydrocarbons. "Wood-preserving wastes" could be grouped under a term such as phenols and PAHs.
- 8) A Glossary of Terms and Acronyms in the Appendix of the Strategy Document Would be Helpful for the Reader. There are many terms and acronyms used throughout the Strategy Document and the Tables. A complete glossary of acronyms and terms would be most helpful as an attachment or appendix to the Strategy Document and would facilitate understanding for the general reading audience. In fact, most Agency documents would do well to make the use of a glossary of terms and acronyms a standard practice, as is done with the SAB reports.

APPENDIX A - GLOSSARY OF TERMS AND ACRONYMS

BRRS	-	BIOREMEDIATION RESEARCH REVIEW SUBCOMMITTEE (EEC/SAB/EPA) (ALSO REFERRED TO AS THE SUBCOMMITTEE)
CERCLA	-	COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT (ALSO KNOWN AS "SUPERFUND")
DOD	-	DEPARTMENT OF DEFENSE
DOE	-	DEPARTMENT OF ENERGY
DSSs	-	DECISION SUPPORT SYSTEMS
EEC	-	ENVIRONMENTAL ENGINEERING COMMITTEE (SAB/EPA)
EPA	-	U.S. ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA, or "THE AGENCY")
FY	-	FISCAL YEAR
HAH	-	HALOGENATED AROMATIC HYDROCARBONS
HSRCs	-	HAZARDOUS SUBSTANCES RESEARCH CENTERS
LOCI	-	UNDERGROUND STORAGE TANK CONCEPTUAL MODEL DEVELOPED BY THE U.S. EPA/ORD RISK REDUCTION ENGINEERING LABORATORY
NSF	-	NATIONAL SCIENCE FOUNDATION
OEETD	-	OFFICE OF ENVIRONMENTAL ENGINEERING AND TECHNOLOGY DEMONSTRATION
ORD	-	OFFICE OF RESEARCH AND DEVELOPMENT, U.S. EPA
PAHs	-	POLYCYCLIC AROMATIC HYDROCARBONS
pH	-	NEGATIVE LOG OF HYDROGEN ION CONCENTRATION
RCRA	-	RESOURCE CONSERVATION AND RECOVERY ACT
SAB	-	SCIENCE ADVISORY BOARD (EPA)
TCLP	-	TOXICITY CHARACTERISTIC LEACHING PROCEDURE
TRD	-	TECHNICAL RESOURCE DOCUMENT
UST	-	UNDERGROUND STORAGE TANK
US	-	UNITED STATES

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