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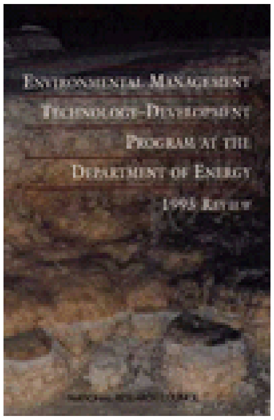

Environmental Management Technology-Development Program at the Department of Energy: 1995 Review

Committee on Environmental Management Technologies, National Research Council

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Environmental Management Technology-Development Program at the Department of Energy 1995 Review

Committee on Environmental Management Technologies
Board on Radioactive Waste Management
Commission on Geosciences, Environment, and Resources
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

The U.S. Department of Energy (DOE) established its Office of Environmental Management (EM) in November 1989. The primary goal of the EM program is to clean up the legacy of environmental pollution at DOE weapons complex facilities throughout the nation. This undertaking costs billions of dollars each year, and its magnitude and complexity demand that related technology development and use be optimized and cost effective, while also reducing risks to public health and meeting program goals and schedules.

At the request of DOE's Assistant Secretary for Environmental Management, Thomas Grumbly, the National Research Council (NRC) formed the Committee on Environmental Management Technologies (CEMT) to provide DOE-EM with continuing independent review and recommendations on technology development and use. (CEMT's formal Statement of Task is presented in Appendix B.) The CEMT membership (see biographical sketches in Appendix C) was constituted to represent the broad span of disciplines required to address its charge. This report is intended to be helpful to those responsible for managing DOE's large and important technology-development programs. The committee will produce a yearly report; the first, published in 1995, describes CEMT's 1994 activities.

CEMT convened its first meeting in December 1994, in Washington, D.C. Open sessions included presentations by NRC Chairman Bruce Alberts, Assistant Secretary for DOE-EM Thomas Grumbly, and DOE Deputy Assistant Secretaries for Environmental Restoration, Waste Management, Technology Development, and Facility Transition and Management. Three invited talks by non-U.S. scientists provided some international perspectives on tank wastes, ground-water cleanup, and mixed wastes. In addition, representatives of DOE-EM's five focus areas gave detailed accounts of their ongoing and proposed work. These five focus areas form the core organization of the DOE-EM tasks: (1) Contaminant Plume Containment and Remediation; (2) Landfill Stabilization; (3) High-Level Radioactive Waste Tank

Remediation; (4) Mixed-Waste Characterization, Treatment and Disposal; and (5) Facility Transitioning, Decommissioning and Final Disposition.

During 1995, CEMT met three times: March 22-23 at the National Research Council, Washington, D.C.; July 31-August 1 at the J. Erik Jonsson Woods Hole Center in Woods Hole, Mass.; and December 6-8 at the Arnold and Mabel Beckman Center in Irvine, Calif. During the first meeting, presentations were made by senior officials from the DOE, the U.S. Department of Defense, and the U.S. Environmental Protection Agency. At the second meeting, presentations were made by DOE officials and members of organizations carrying out waste remediation functions at the Savannah River Site. At its third meeting, CEMT reviewed the reports of its five subcommittees, received a report from a DOE representative on what actions had been taken in response to the recommendations of CEMT's report for 1994 activities, and prepared this report for 1995 activities.

CEMT wishes to thank members of the DOE-EM staff for their cooperation in presenting material to the committee and its subcommittees, and members of the NRC staff, especially K. T. Thomas, Thomas Kiess, Susan B. Mockler, Patricia A. Jones, and Robin L. Allen, for their support.

EDWIN E. KINTNER
CHAIR, CEMT

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Executive Summary

The U.S. Department of Energy (DOE) established its office of Environmental Management (EM) in 1989 to oversee the cleanup of hazardous materials at DOE facilities throughout the United States. Due to the public health risks associated with some of those hazardous materials and the high costs of remediation, technologies developed and used for environmental management must be cost effective and achievable with acceptable risks. To help ensure that these critical objectives are achieved, DOE's Assistant Secretary for Environmental Management, Thomas Grumbly, asked the National Research Council (NRC) to review and evaluate the DOE's Environmental Management (DOE-EM) technology-development program. In response to this request, the NRC's Committee on Environmental Management Technologies (CEMT) was established in 1994 to provide DOE-EM with continuing independent review and recommendations on technology development and use.

In addition to the main committee, CEMT formed five subcommittees to address the unique issues relevant to developing technologies for environmental remediation. These five areas, which parallel DOE's focus areas, are defined in the Introduction of this report.

Based on DOE presentations, discussions with DOE staff, and review of DOE documents concerning technology development within EM, the committee has concluded that the DOE-EM's overall program approach based on the focus areas and cross-cutting technologies is a promising one. During the past year, however, DOE-EM has made only limited progress in implementing the recommendations of the committee's first-year report (NRC, 1995). A great deal more needs to be done before the DOE-EM has a vital, focused, and coordinated technology-development program sufficient to support the technically and organizationally complex waste-remediation program effectively. In this report, a number of steps that should be taken to strengthen the DOE-EM program are discussed.

Conclusions and recommendations for each of DOE's five focus areas, as well as some cross-cutting areas, are presented in Chapter 3, whereas, the working papers in Appendix A include more detailed discussions. Based on these specific conclusions and recommendations, five significant points are highlighted that should be helpful to DOE, particularly, in its efforts to further technology-development activities in environmental management. Specific actions that DOE needs to take are to

- develop and implement quantitative criteria by which technology-development efforts can be prioritized and success can be measured;
- carefully consider the waste streams (including those from remediation efforts to their eventual disposition) in determining adequate technology-development needs;
- systematically assess and document previous and current efforts to develop and apply technologies using the quantitative criteria mentioned above;
- apply effective, external peer review in the selection, evaluation, and prioritization of its projects; and
- improve its system for information gathering and documentation on technologies that are available and under development by other relevant organizations in the United States and abroad.

These points and other recommendations are more fully discussed in Chapter 2.

The EM technology-development program has a major role in determining whether the entire DOE waste-remediation program is carried out well with regard to needs, risk reduction, cost, schedule, effectiveness, and satisfaction. As an indication of its importance, the program, now five years old, has enjoyed stable funding levels, while the budgets of other DOE programs have been reduced. The committee notes a number of items indicative of improvements in the technology-development activities of EM, and recognizes the major effort involved in implementing a program of this scope and magnitude. After observations during 1995, however, CEMT believes that major improvements are needed in the fundamental management processes if the EM research and technology-development program is to meet its responsibilities to the DOE and the public. The recommendations of this report are offered as constructive suggestions to a program that has many competing internal agendas and outside influences.

1

Introduction

At the request of the U.S. Department of Energy's Assistant Secretary for Environmental Management (DOE-EM), the National Research Council (NRC) formed the Committee on Environmental Management Technologies (CEMT) in 1994 to provide independent review and recommendations to DOE-EM on scientific and technical issues for the environmental management of DOE's weapons complex facilities.

In keeping with the statement of task, CEMT has the following responsibilities:

- review and evaluate DOE-EM's technology-development programs, including guidelines, methodologies, protocols, demonstrations, and applications, with attention to the most important problems facing DOE-EM;
- identify, review, and recommend, as appropriate, new technical criteria and emerging technologies in environmental management that are most relevant to DOE-EM;
- review technology transfer and commercialization issues for DOE-EM technology programs; and
- issue reports, recommendations, and options for DOE-EM's technology development, including substantive annual reports on its activities undertaken during the year and other topical reports when appropriate.

To address the breadth of activities in the EM program, CEMT formed five subcommittees that parallel DOE's five focus areas. The focus areas, which form the basis of DOE's new integrated team structure established in 1994, are: (1) Contaminant Plume Containment and Remediation ("Plumes"); (2) Landfill Stabilization ("Landfills"); (3) High-Level Waste in Tanks ("Tanks"); (4) Mixed-

Waste Characterization, Treatment, and Disposal ("Mixed Wastes"); and (5) Facility Transitioning, Decommissioning and Final Disposition ("D&D"). In addition to the five focus areas, CEMT has also reviewed, in a limited fashion, pertinent cross-cutting areas, including characterization, monitoring and sensor technology; efficient separations and processing; robotics; and disposal.

The role of CEMT is largely programmatic and deals with the overarching issues of technology development, implementation and evaluation, with a focus on the management and soundness of DOE-EM initiatives. An additional role of CEMT is to evaluate specific technologies of importance. Although the subcommittees provide technical information to CEMT, they are not acting as technical project review agents in the focus areas.

During their various meetings, CEMT and its subcommittees were exposed to a cross section of issues related to technology development and were briefed by representatives from DOE headquarters, academia, private industry, national laboratories, and public policy and public interest groups. The topics discussed at these meetings included a variety of technical approaches for management of DOE-EM's complex cleanup, as well as the details of specific technologies.

The different stages of development of DOE's focus areas are reflected in the subcommittee reports (Appendix A), which have been reviewed and accepted by the full CEMT. Because these reports were compiled by five distinct groups, they are presented in various formats. The subcommittee reports should be regarded as works in progress—the preliminary findings are limited by the short time that the subcommittees have been in operation. The five subcommittees have additional meetings scheduled for 1996—generally, at major DOE sites having both R&D and remediation operations. The additional information to be collected at these meetings may augment or modify some of the specific findings presented in the subcommittee reports.

In the next few years, CEMT will continue its study as outlined in its statement of task. The committee will look at issues affecting technology development, including the status of technologies available, strategic goals, performance measures, prioritization schemes, barriers to achieving goals, criteria for technology development, and changes in various regulations and policies.

The limited time available to the committee makes it impractical for the CEMT to be fully aware of all aspects of DOE technology-development activities throughout the weapons complex. Nevertheless, the committee believes that some general principles are now obvious. These conclusions and recommendations are given in Chapter 2.

During the process of evaluating DOE-EM's technology-development program, CEMT has noted several activities that indicate that DOE-EM has made some progress in improving the program. These activities, noted below, should continue.

1. Useful steps seem to be in process to make cooperation among DOE-EM's Waste Management program (EM-30), Environmental Restoration program

(EM–40), and Technology–development program (EM–50) successful in improving technology development throughout EM.

2. Successful LASAGNA™[1] technology demonstrations involving industry, DOE organizations, and EPA offer the promise that it will be a useful technology for remediation of solvents in the subsurface at some sites within the weapons complex.
3. Progress has been made in determining the value of plasma arc and plasma hearth vitrification of mixed wastes and in comparative studies of thermal and nonthermal technologies.
4. The efficient separations and processing cross–cutting area has leveraged the expertise of industry in developing innovative processes for the separation of ^{137}Cs from radioactive wastes.
5. The Digface[2] characterization system is a useful development that uses available site information while retaining the flexibility to acquire information as excavation proceeds. (see Appendix A, Landfills).

The CEMT recognizes the difficulties facing DOE in implementing technology–development programs of this scope and magnitude. The committee is hopeful that this 1995 report will be helpful to those responsible for managing the EM Research and Development (R&D) program and looks forward to providing further support and guidance in subsequent years. The 1995 report has focused more in management and related areas; the 1996 report is expected to be more technology oriented.

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[1] The LASAGNA™ technology, a trademark of the Monsanto Company, is a system or combination of components in a configuration of electrodes and degradation zones that permits in-situ treatment of contaminants in low-permeability environments. Monsanto Company has coined the word LASAGNA to identify its products and services based on this integrated in-situ remediation technology.

[2] The Digface characterization project being developed by the Idaho National Engineering Laboratory (INEL), Ecology International, and Rust Geotech Inc., is an integrated demonstration of multiple sensors that can be used as part of a retrieval effort. The Digface characterization technology will allow continuous and continually improving monitoring and characterization of the site being remediated.

2

Improving the Development of Environmental Management Technologies

In its deliberations during 1995 and its review of the subcommittee reports attached in Appendix A, CEMT identified five significant points that DOE should address if it is to manage the development of environmental management technologies effectively.

IDENTIFICATION, SELECTION, AND PRIORITIZATION OF TECHNOLOGY-DEVELOPMENT INVESTMENTS

In an environment of severely constrained federal budgets, setting clear priorities for technology-development investments has become increasingly important. In a previous report by this committee evaluating the development of environmental-management technologies (NRC, 1995), DOE was encouraged to focus technology development on clearly identified problems and to consider systematic use of comparative risk and risk/benefit assessment in evaluating environmental-management alternatives that form the basis for technology-development needs. During the DOE briefings and site visits, CEMT has not seen evidence that this systematic evaluation of alternatives or that any such approach to prioritizing DOE-EM's technology investments based on need, risk, and other important factors has been implemented.

A systematic evaluation of environmental-management technologies must be an underlying framework for prioritizing technology needs. A framework that has worked well for complex technological systems is that of a *structured set of problem/solution scenarios* responding to a *needs assessment*. These scenarios should be evaluated against *explicit quantitative criteria*, based on a robust set of *criteria performance measures* such as risks, costs, schedule, and benefits. Embodied in each scenario are many factors, including different technology requirements, safety impacts, cost implications, and environmental impacts (see Figure 1). The basic approach for prioritizing technology development needs in this manner is outlined below:

- develop and perform an assessment of needs for a given problem or issue;
- develop a comprehensive set of scenarios for different solutions to each problem or issue, covering the major steps from characterization to disposal;
- screen the scenarios to a manageable few, utilizing appropriate screening criteria based on the chosen performance measures;
- quantify the performance measures of an appropriate set of screened scenarios;
- rank the scenarios based on the values assigned to the performance measures; and
- derive the technology-development needs from this ranking of scenarios.

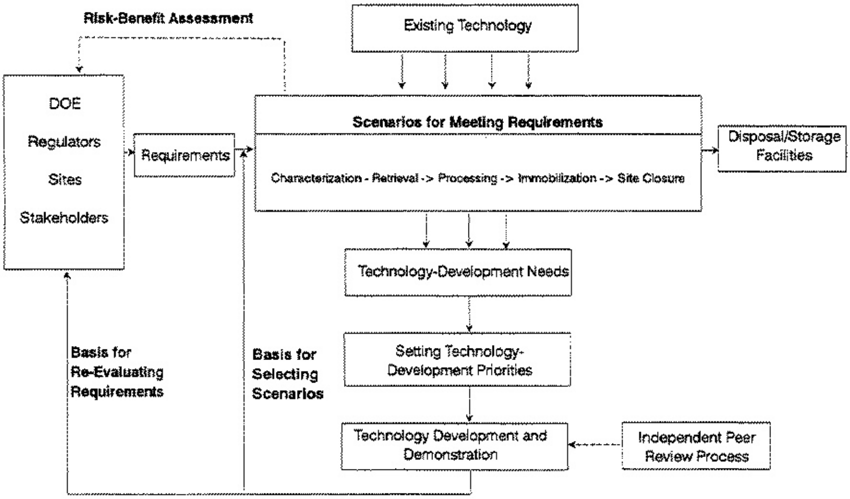

Figure 1:
Relationship of Technology Development to Waste Remediation

This process would ensure that the technology needs identified are related to known problems because the scenarios are based on actual problems that must be solved. The process would also assess the relative value of developing technologies that perform as assumed in the scenarios.

Once the technology needs have been identified, evaluated, and prioritized, additional factors on performance measures may be considered in setting priorities among the available technology-development investment options. Additional performance measures could include the likelihood of success and the need for a balanced portfolio of technology-development investments (i.e., a mix of near-term, low-risk investments and longer-term, high-risk, high-payoff investments).

Recommendation: DOE should develop and rank remediation scenarios leading to a prioritized list of technology needs as noted above. The scenarios should be structured to define only the major steps from characterization through disposal (or storage) and to highlight only the major choices to be made. It is important that the scenarios be presented clearly; too much detail can obscure the basic issues.

CAREFUL CONSIDERATION OF WASTE STREAMS AND THEIR FINAL DISPOSAL

The need to establish objectives for remediation and disposal also was emphasized in the previous NRC report (NRC, 1995), which stated the following (p. 3):

> While DOE-EM briefers to the committee and submitted documents have identified technologies that will or might be developed, there has been little discussion yet of quantifiable end goals for radioactive contaminants in such terms as final volumes, volume reductions, end product characteristics, and environmental impacts. The levels to which cleanup is required at the sites in which the remediation takes place need reference levels for residual contamination, and specification of future uses for the sites. The criteria for residual impacts on population and the environment do not appear adequately addressed. Development of such criteria has an important bearing on the final cost and feasibility of remedial approaches.

Further, the report stated (p. 4):

> Very little was said [by the presenters] about a crucial component of the overall environmental remediation system, namely, the final destination of removed/immobilized waste material and its separated fractions. Modes of treatment,

> conditioning, and immobilization of wastes are not totally independent from the characteristics of the disposal environment and have to be factored as part of the total system in planning technology development.

Based on DOE presentations, discussions with DOE staff, and review of DOE documents, the committee concludes that these considerations do not appear to have been part of the technology-development program to date. Until such goals are established, it will be impossible to develop an effective focused research and development program with definitive end points.

The committee is aware of the difficulty in the present regulatory and public climate of establishing fixed, precise objectives. Nevertheless, the lack of such objectives, even if tentative, is adversely affecting attempts to organize and conduct focused and timely technology development. The end points and technologies must be factored into the system early and with reasonable certainty if the program is to be carried out in a cost-effective and timely manner and with the greatest safety to the public. This process requires, at the very least, that working hypotheses be established by DOE with or without the help of other interested parties as to waste streams and waste-disposal conditions. The eventual environmental impact of waste-management practices results from the combined characteristics of waste-treatment end products, the source term, and the disposal environment. The impact also depends on the behavior of future societies, particularly with respect to various ways in which they inadvertently might intrude into the waste-disposal facility. In fact, most performance assessments show that human intrusion is the dominant pathway of exposure. The types of human intrusion scenarios that are assumed are a matter of policy.

Recommendation: A greater focus should be put on defining the required characteristics of the waste streams and the nature of the ultimate disposal sites, even if tentative and only as working targets, is necessary to manage effectively the EM technology-development program (see Appendix A for more details).

PROJECT ASSESSMENT AND EVALUATION

A previous NRC report (NRC, 1995) states that, "The environmental remediation of the DOE weapons complex is of such a magnitude that in many ways it is an experiment." It is not simply a task of applying known technology with well-understood effectiveness to well-defined cleanup problems. In many cases, the DOE complex presents unique waste management and remediation problems for which there is no prior experience, and in others, it faces more common problems (e.g., ground water contaminated with dense nonaqueous phase liquid [DNAPL]) for which there are no current satisfactory remediation options. This view that the DOE environmental remediation program is the largest nondefense technology-development program in the country, was supported by Assistant Secretary for DOE-EM Thomas Grumbly in CEMT's opening session.

Recognizing the experimental nature of the DOE cleanup problem, the previous NRC report (NRC, 1995, p. 3) pointed out that ". . .the initial phases of technology development should be considered an exploration of the means to meet environmental remediation requirements. Remediation efforts now underway are also part of the iterative process of technology development and application, which should be recognized by the focus area groups and the steering committee in their integrated team work efforts, and by feedback mechanisms in the system so that future decisions can benefit."

For effective feedback of lessons learned, progress and results must be documented. Performance measures are needed for the technical-development program. In a study of best R&D management practices in private industry[3], more than 50 percent of the respondents put "Learn from post-project audits" in the top third of R&D practices with the greatest potential gain relative to the effort involved.

Systematic evaluation of performance measures is needed in both the technology R&D and technology-application phases, as discussed below.

1. *The R&D phase.* There should be clear criteria for success or failure of technology R&D efforts, and those efforts should be evaluated while they are being conducted so that unpromising research can be terminated. Little evidence has been seen within EM-50 of any systematic approach to such assessment and evaluation. For example, DOE plans four large-scale decontamination and decommissioning (D&D) demonstrations during the next two years, but it is not clear to the committee how these demonstrations will be evaluated and documented to capitalize on their successes and failures for use in future D&D activities.
2. *The application phase.* A technology that appears to work well in the demonstration phase may experience difficulties in large-scale application. For that reason, monitoring of the results of such applications is an important part of an assessment and evaluation program. For example, CEMT's Landfills Subcommittee recommends a focused program of long-term performance assessment of barrier walls and caps, because these are key components of the present DOE environmental-restoration strategy. If privatization is aggressively pursued, it will be essential that documentation of the evaluation and assessment process and the corresponding performance measures be built into the contractual expectations for successful bidders.

It is important to recognize that these evaluations of effectiveness are a necessary part of the learning process and should not be viewed as being intended to fix blame for "failures." The aim is to learn from these demonstrations, whether or

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[3] "Lessons Learned from Industrial R&D Management," presentation to the committee by Dr. Michael M. Menke, Strategic Decisions Group, Menlo Park, Calif. on December 6, 1995 at Irvine, California. This study involved a survey of 200 R&D business executives to determine which companies they believed managed R&D best and what areas of

not they are judged to be successes. A program of technology development necessarily includes failures as well as successes along the way, and the failures provide valuable information.

Explicit evaluation procedures with quantitative criteria are needed as a basis for determining which projects should be continued and which should be terminated (more detail is provided in the section on prioritization). Termination of R&D projects has been identified by the Industrial Research Institute as one of 12 high-potential activities for improving R&D return.[4]

In this connection, clear identification and evaluation of outcomes would provide a better basis for organizational performance measures than a simple count of completed activities. For example, EM-50 might be scored by considering the number of technological challenges overcome, rather than simply the number of demonstrations conducted, as is now the case in some areas. Similarly, EM-40 might be scored by considering the number of remediation problems positively affected (in risk and/or cost reduction) by implementation of better-than-baseline technology. Use of such performance-based measures would contribute to orienting the DOE organizations toward problem solving.

DOE's ability to apply the results of technology-development efforts will depend to a significant extent on acceptance by outside parties, most importantly, the responsible regulatory authorities and the affected communities and states. For this reason, the committee stated in its previous report (NRC, 1995) that it would be desirable to establish a process "whereby new technology-development efforts and their anticipated results can be taken into account in renegotiating tripartite agreements." The committee believes that the likelihood of acceptance by key outside parties can be enhanced if they are involved in appropriate ways in the process of selecting technologies for development and, of particular importance, the process of assessing and evaluating the results of development and demonstration efforts.

Recommendation: DOE should develop clear protocols and performance measures for assessing and documenting the effectiveness of technology-development projects and field applications. Explicit and measurable criteria for success and procedures for evaluation must be included, including external peer review. Specific evaluation procedures should be included as an integral part of projects, and the results of these evaluations should be documented. These procedures should be applied to current and future projects to identify "lessons learned" that could be applied in future decisions. DOE also should develop a process to disseminate the results of such evaluations throughout the complex to ensure that the lessons are indeed "learned" by decision makers.

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improvement they thought most important. This study includes interviews with 22 organizations selected for excellent R&D decision making and identification of 45 "best practices" for R&D decision quality, tests of the findings with over 100 R&D executives in the United States and Europe, and reconfirmation of the findings in a joint survey with the Industrial Research Institute's Quality Director's Network.

[4] "Improving the Return on Research and Development," Industrial Research Institute, 1984, cited by Michael Menke, Strategic Decisions Group, in a presentation to CEMT, December 6, 1995, Irvine, Calif.

PEER REVIEW

Review of the DOE-EM guidance document on merit review and peer evaluation issued in late 1994 (USDOE, 1994a) provides little evidence that a credible external peer-review system is in place to help guide environmental technology development in the EM program. The external peer-review system needed for this guidance must be separate from, and in addition to, the National Research Council's ongoing role of providing overall programmatic review, because the NRC is not a formal reviewer requiring follow-up by DOE-EM.

Peer review is accepted and widely used as a management mechanism to enhance the quality of R&D programs. To be credible and effective, the peer-review process must assure the technical qualifications of the reviewers and avoid real or perceived conflicts of interest that might affect the outcome. Agencies such as the National Science Foundation (NSF), the Environmental Protection Agency (EPA), the National Institutes of Health (NIH), and the National Aeronautics and Space Administration (NASA) have well-established peer-review procedures (e.g., the Science Advisory Board of the EPA) that have been thoroughly tested and could serve as models for DOE's technology-development program.

High priority should be given to the development and implementation of a rigorous external peer-review process to enhance the scientific and technical quality of the EM technology-development program in the near term. To be most effective, procedures should be standardized as far as possible across all functional elements of EM and especially for all focus areas. The technology review process should be tied to and coordinated with DOE's current system of stages or "gates" that determine the level of maturation for technology development (see Chapter 3, Landfills Focus Area). It is appropriate that internal review should include site representation and technology users to ensure that technology-development efforts are timely and responsive to DOE problem-solving needs. However, external peer review is the appropriate mechanism to ensure the technical soundness and merit of specific projects. Selection of external peer reviewers should be based only on technical qualifications.

Additional mechanisms, such as citizen groups and regulators, should be used to obtain the input of stakeholders. Federal agencies have frequently found it useful to seek the advice of independent scientific and technical groups such as the American Physical Society (APS), the Federation of American Societies for Experimental Biology (FASEB), and the American Institute of Biological Science (AIBS) to identify qualified peer reviewers. Such external technical involvement helps an agency establish and maintain the credibility and competence of its scientific and technological programs.

External peer review can also provide a mechanism for consistent guidance. Each focus area should select qualified experts to serve as peer reviewers on a continuing basis for an extended period. Such an approach would provide long-term guidance by allowing the experts to track decisions made in the DOE remedial technology-development program. Although some focus areas have technical review panels with membership outside of DOE, these panels will not serve the same role as that of external peer reviews.

Peer review can be conducted in many forms: project-focused rapid response, specific technology area review, and comprehensive research needs assessment. By making use of this full range of review modes, DOE-EM can avail itself of constructive criticism without slowing progress toward its technology-development goals.

A helpful associated activity is expert elicitation, which uses expert judgment in a controlled and structured manner to enhance the knowledge base for making a decision. Expert elicitation is being used to provide important input to the performance assessments of the potential repositories and facilities for the disposal and storage of nuclear waste. Agencies such as DOE and the U.S. Nuclear Regulatory Commission (USNRC) are developing detailed guidance documents based on their experiences with expert elicitation. Because of the interrelationship between peer review and expert elicitation, the committee intends to review these guidance documents in future considerations of the peer-review process.

Peer review is being applied to some current programs, such as those of the Landfills Focus Area. Examples of such activities are the review of technology projects presented at the *TRU (transuranic waste), TRU Mixed, and Mixed Low-Level Waste Treatment Technologies Technical Peer Review* (November 13–15, 1995, in Dallas, Tex.), and the *Non-Destructive Assay/Non-Destructive Evaluation (NDA/NDE) Review* (January 25–26, 1996, in Pittsburgh, Pa.) Another documented effort is the recently completed review of a microbial filter project, prior to the commitment of funds for development costs in later stages of development. These examples illustrate that peer review can be used to help guide environmental technology development throughout the EM program.

The committee emphasizes that DOE needs an effective external peer-review process and that it should be implemented in a uniform, consistent manner.

Recommendation: DOE-EM needs to develop and uniformly apply a standardized peer-review process designed to assess the following parameters in all five focus areas: the appropriateness of the identified technology needs, the appropriateness of projects to meet specific technology needs, and the soundness of the technical approach being used or proposed on separate projects.

INFORMATION GATHERING ON TECHNOLOGIES AVAILABLE AND BEING DEVELOPED IN THE UNITED STATES AND ABROAD

The DOE-EM program needs to improve its awareness and understanding of the availability and development status of technologies applicable to its multiple waste-management problems, not only in its own laboratories and contract organizations, but throughout industry, universities, and worldwide. It should be stated that DOE-EM is not alone in this deficiency; U.S. industry lacks this focus as well. DOE-EM needs this knowledge of available technologies for the three main purposes that follow:

- to compare its technology needs to the status of technology, leading to the identification of technology gaps that require development efforts;
- to ascertain the extent to which proven technologies that exist in other agencies, the private sector, or overseas might be applicable to a specific problem, thus providing the possibility that further technology development is not required; and
- to assess the potential for commercialization and collaborative development of the technologies being considered for development.

Review of the DOE program and documents have shown that DOE's efforts to keep abreast of the status of technologies related to its needs have been inadequate. Technologies that already exist have been redeveloped, more so in areas related to wastes containing hazardous chemicals (e.g., DNAPL issues), than in areas related to wastes containing radionuclides. In addition, developers routinely are urged to pursue commercialization when many technologies are only applicable to unique DOE wastes or situations. There is also a risk that necessary technology development may be affected adversely, using the rationale that privatization could meet the needs, despite the fact that environmental cleanup conditions are unique to the DOE system and there is no incentive for the private sector to develop technologies.

Recommendation: DOE-EM should undertake an explicit effort to inventory the status of technologies relevant to its interests and disseminate the results throughout the program. This inventory should consider both the wastes to be addressed and the conditions (e.g., requirements for remote operation). It should cover both domestic and international venues and all sectors (government, commercial, academic). Such an inventory will allow DOE-EM to identify those research areas where solutions or partial solutions are already available from external sources, as well as those development areas where major DOE-EM technology-development efforts are required.

3

Technology Development in DOE: Focus Areas and Cross-Cutting Areas

FOCUS AREAS

The five CEMT subcommittees reviewed and evaluated the waste-management technology-development activities in the five focus areas of DOE's EM-50 program. Each of the subcommittees has met with DOE headquarters and field staff who have responsibilities for a focus area. In addition, three of the subcommittees have visited the Savannah River Site (SRS) near Aiken, S.C., where waste-management R&D remediation operations are being conducted.

The subcommittees have studied DOE focus-area planning documents and interviewed several levels of management to assess the applicability and quality of the technology-development programs. The subcommittee reports in Appendix A contain the substance of their assessments, including conclusions and recommendations concerning the work of the focus areas. Some of the conclusions and recommendations in the five reports are strikingly similar and apply to the activities of all five of the focus areas and cross-cutting areas.

In the focus and cross-cutting area studies, some general findings of technology development emerged. These same findings are described as the five major points highlighted in Chapter 2. Some of the specific recommendations for the focus and cross-cutting areas are discussed below.

Recommendations: Plumes Focus Area

1. The Plumes Focus Area should identify the major risk and cost drivers associated with remediation of DOE contaminant plumes and develop an integrated systems approach to drive technology development that meets the EM strategic goals of risk reduction, cost efficiency, environmental restoration, and regulatory compliance.

2. The strategic goal recorded in the *Environmental Management Program Strategic Plan* (USDOE, 1994b) highlights the goal of reducing plume characterization expenditures by 50 percent by fiscal year 1997, a goal that seems optimistic. An integrated systems approach is recommended because it might enable DOE to achieve such a cost reduction while still obtaining sufficient characterization data. This recommendation is especially important, because numerous contaminant plumes have not been adequately characterized yet.
3. An assessment should be made of what has been accomplished and learned so far in the Plumes Focus Area. Each remediation or demonstration could be probed to identify successes and lessons learned, addressing the questions of what it did and did not accomplish, and why. These lessons learned could provide valuable scientific data in charting progress and learning about remediation attempts and could serve as a guide for future approaches. It is important to look at all learning experiences as well as successes, because these experiences have valuable information content. Eventually, a good rationale for technology development could be developed, ideally based on both field data and theoretical models.
4. DOE should establish a process for developing specific cleanup goals for each of its contaminated sites within the regulatory framework, because the appropriate approach for remediation of a site depends upon the cleanup goals, intended land use, and technical impracticability issues.

Recommendations: Landfills Focus Area

1. Greater effort is needed in long-term performance testing and monitoring of engineered containment techniques and systems, including covers, caps, barrier walls, and floors.
2. A *problem-solving orientation* in technology development is advocated. The subcommittee acknowledges the focus area's efforts to date in these areas and offers three preliminary suggestions to improve and help implement the problem-solving orientation:

a) A ranking/categorization for landfill-related problems based on relative risk would be useful to drive technology development in DOE. These analyses need not use sophisticated models and may already exist to some degree in DOE literature.

b) Technology needs should be established from this risk prioritization and used to identify priority technical tasks.

c) These technical tasks would then be organized into product lines, based on technology rather than the waste type (e.g., TRU/Mixed Waste-Arid; TRU/Mixed Waste-Non-Arid; Low-Level Waste/Other-Arid; Low-Level Waste/Other-Non-Arid) as is currently the practice. The proposed technology grouping would include five product lines:

i) characterization (or assessment),

ii) retrieval (encompassing technology development for any kind of retrieval operations contemplated),

iii) treatment (including both in-and ex-situ methods),
iv) containment and monitoring, and
v) systems integration and design.

3. Each technical project would benefit from clearly established goals, a strategic plan to guide development, and an action plan describing how these strategic goals are to be met. DOE's current system of "gate" reviews is supported and should be used more broadly throughout the Landfills Focus Area as a helpful tool in technology-development planning. Gate reviews are DOE's system of determining the level of maturation for specific technologies. Gates represent the successive stages of technology development in EM-50's "technology maturation model" used to track the project they fund. For instance, the lower-level gates (1–3) correspond to R&D, gate 4 is the stage where the decision whether or not to continue funding the technology is made, and higher-level gates (5 and 6) include demonstration and the final stage of implementation.

Recommendations: High-Level Waste in Tanks Focus Area

1. Substantial technology-development needs remain to be addressed if the high-level waste in tanks is to be successfully remediated. The DOE should continue to support a balanced technology-development program integrated across all involved organizations, including EM-30,-40, and-50, and Energy Research.
2. A number of important technology needs related to managing high-level waste in tanks are common to the four DOE sites that have alkaline nitrate supernatant-saltcake-sludge wastes. For the most part, the needs of the Idaho National Engineering Laboratory (INEL) site are expected to be significantly different from other sites because the waste is acidic. Integrating technology-development efforts would be desirable in order to develop technologies in a cost-effective manner and to share the results to the extent they are applicable at multiple sites. However, the subcommittee has not yet had the opportunity to evaluate the effectiveness of the existing focus area.
3. Program requirements and constraints for technology development should be specifically defined. Issues that should be considered are waste characterization, retrieval from the tanks, processing, immobilization, site closure, and disposal.

Recommendations: Mixed-Wastes Focus Area

1. Because waste treatment is only one, albeit essential, step of the management of radioactive mixed wastes, decisions related to selection of a treatment technology or to development of a new technology should be made in the perspective of optimization of the full waste-management scheme, which includes disposal of the

treated end products. DOE-EM should give full consideration to the characteristics of the final waste form in the perspective of its potential disposal environment. Ultimately, treatment technologies must be evaluated as a total system and in lifecycle context.[5]

2. Selection of treatment technology and decisions to develop new technologies should be based on perceived needs associated with specific waste streams and potential advantages with regard to various issues such as types and quantities of wastes, quality criteria that define the end products and their use, and cost. Application of available and near-mature technologies may still leave some waste-treatment problems unsolved and, for the latter, new approaches may be required. Development of new treatment technologies should focus on adequacy and cost effectiveness of existing technologies for mixed-waste treatment, rather than on new, potentially applicable treatment technologies for mixed-waste streams.
3. Adequate characterization of mixed wastes is a critical element for successful and cost-effective implementation of mixed-waste management. Techniques used for characterization of mixed wastes should be adapted and limited to meet the essential requirements of the treatment processes and waste-management systems.

Recommendations: Decontamination and Decommissioning Focus Area

1. DOE EM-50 has stated to the D&D Subcommittee that new technologies are needed to perform D&D tasks in safer, better, cheaper, and faster ways than are possible with presently available technologies. However, no documentation of the basis for this premise, which is the justification for the entire technology-development program, has been provided to the subcommittee or identified. Further, no basis was found for establishing the level to which sites should be decontaminated other than the need to comply with statutory, regulatory, and contractual requirements. End-use risk and cost are also major drivers. The tripartite agreements between the state of Washington, EPA, and DOE have been put in place largely without consideration of end use or rigorous risk assessment. As a result, existing statutes and regulations have been applied without adequate analysis of actual risk to populations and the environment.

   DOE should establish and document criteria to compare and evaluate the effectiveness of existing and candidate technologies and to identify deficiencies in these technologies. Such criteria should include cost effectiveness, probability of success, time of availability, secondary waste streams, and risk to operators and the public. After this evaluation has been accomplished, the basis for projecting the need for and/or the superiority of future technologies should be stated explicitly. The

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[5] "Total system" means all steps of waste management from generation to disposal. "Life cycle" refers to all costs and efforts related to the application of a technology, i.e., R&D, delays due to new R&D and demonstration, licensing/acceptance, implementation, etc. Some overlap may exist between the two notions, but they are not identical.

process should start with a needs assessment for the D&D Focus Area and should identify available technologies, technology gaps, and criteria for establishing priorities. DOE is also in urgent need of defining criteria by which to decontaminate sites on a "necessary and sufficient" basis within regulatory constraints. Such an exercise might indicate that current technologies are adequate to meet many cost and schedule targets. External peer review should be applied to each of these steps as appropriate.

2. The D&D Focus Area 1995 Strategic Plan's emphasis on relatively mature technologies and large-scale demonstrations, is too narrowly focused (USDOE, 1994b). The D&D Focus Area should revise its strategic plan to provide for a comprehensive D&D technology-development program. This plan should specify a process that will yield a systematic assessment of D&D needs and available technologies, identify technology gaps, develop criteria for establishing priorities, and justify each demonstration project that will be funded and executed. This effort should include a balanced program of basic and applied research, exploratory and advanced development, engineering design, demonstration, and implementation. This strategic plan should also be flexible, including provisions for future periodic revisions as new data and experiences are gained.
3. DOE should address planning in terms of a process, as many organizations have found that the most valuable aspect of any strategic-planning exercise is the process of assembling the plan rather than the specific details of the plan. In order for the plans to succeed, DOE decision makers (and not their support contractors) should draft the plans.

DOE managers should set aside time for the planning exercise, which must include the undivided attention of the highest-level decision makers. The plan will succeed best if it has commitment from the highest and broadest levels of management. Different levels of DOE representatives could draft the different plans, but the strategic-planning document must include the highest-level decision makers. Authors of the management plan should include those responsible for managing the plan, and the authors of the implementation plan should include those responsible for implementing the plan. The intent of the above recommendation is to encourage DOE-EM management to identify those activities that are most important and then carry out these high-priority activities effectively.

CROSS-CUTTING AREAS

Appendix A also contains a report on technologies that are generic to and cut across a number of focus-area programs. Three of these technologies are specifically designated by DOE as cross-cutting and have their own budgetary designations. These formally recognized cross-cutting technologies are (1) efficient separations and processing; (2) characterization, monitoring, and sensor technologies; and (3) robotics technology. In addition to these three areas, there are other technologies that are broadly applicable but not managed individually. The section, Cross-Cutting Areas and Technologies of Importance in Appendix A, also contains discussions on areas of this type, i.e., vitrification, incineration, supercritical waste oxidation, and disposal technologies. This report covers the topics in varying degrees of detail but generally cites the reasons for the generic interest in each of the cross-cutting technologies. Some preliminary perspective on the status of technology development and on technological challenges requiring further effort is also included. As with the focus-area reviews, additional information will be collected and assessed in 1996. Recommendations to the cross-cutting areas are discussed below.

Recommendations: Cross-Cutting Areas

1. In planning the research and development needed to support a specific remediation project (e.g., the Hanford tanks), the technology-development activities must be structured to produce an integrated system to deal with all aspects of the project: characterization, retrieval, treatment, stabilization, and disposal. For example, the processes developed for separation of the various waste components during the treatment phase must be compatible with one another as well as with the stabilization technology and with the minimization of cost and risk in disposal and storage. Similarly, the stabilization processes must be designed to consider not only the nature of the treated waste but also the disposal conditions and the duration of the storage period.
2. The DOE EM-50 robotics-development program has a broad range of ongoing projects with planned technology demonstrations and assessments. Documentation and presentations to date show that these projects have not been prioritized and funded according to DOE-EM needs, nor that there has been the required "buy-in" by other DOE organizations (EM-30, EM-40, etc.) for this work. DOE should carefully assess the robotics technology needs of *all* DOE-EM organizations, then plan, schedule, and budget for robotics demonstrations and assessments on a needs-driven basis.

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Appendix A:

Subcommittee Reports

SUBCOMMITTEE ON CONTAMINANT PLUMES

Statement of Task

The Plumes Subcommittee was established to assist the Committee on Environmental Management Technologies (CEMT) in identifying the major technological needs in the Department of Energy's (DOE) Plumes Focus Area. Plumes are an integral component of DOE's Environmental Management (EM) strategy. For the purposes of this report, plumes are defined as chemical and/or radiological contaminants exceeding background concentrations in ground water or soil outside an engineered barrier, including landfills.

This report will review the EM-50 assessment of the relative number, size, and importance of various categories of contaminant plumes at DOE sites, and whether remediation of the various classes of contaminant plumes is possible. In addition, the report will identify the most important technology needs regarding containment and remediation.

Scope of Problem and Needs

Currently, DOE is facing the need for cleanup of contaminant plumes at a dozen sites. However, the magnitude of the problem cannot be fully evaluated without a precise functional definition of a contaminant plume and a characterization of each identified plume in the DOE complex, a characterization that would include contaminant concentrations, volume of the affected area, hydrogeologic considerations, and other relevant information. These plumes contain radionuclides, heavy metals, organic compounds, light nonaqueous phase liquids (LNAPLs), and dense nonaqueous phase liquids (DNAPLs) and are the result of historic open dumping, leaking containers, leaking storage tanks, and other precursor events. The greatest challenge to restoration of these contaminant plumes—and indeed, to many current and future environmental and economic challenges—is finding or developing appropriate technological solutions, many of which may not exist at this time. In addition, the subsurface conditions and the physical and chemical contaminant characteristics may be so complex that complete restoration (or cleanup) may not be possible, and thus only isolation and containment may be feasible (NRC, 1994).

In response to this situation, the DOE has formed the Plumes Focus Area to implement effectively its new approach to overcoming major obstacles in the cleanup of DOE sites through environmental research and technology development. According to DOE briefings, the Plumes Focus Area is the closest of the five focus areas to emulating DOE's "new approach" to conduct a research and technology-development program that will address major obstacles in the restoration of their sites. The focus area's current goal is to oversee the environmental research that would result in the development of technologies to (1) contain plumes that pose imminent environmental and health risks, (2) provide significant advances over conventional pump and treat remediation methods, and (3) remediate soils overlying aquifers where contaminants pose a threat to ground water or human health.

The current focus-area goal seems to center on near-term tactical issues such as remediation needs driven by compliance agreements and the commercialization potential of technology. Thus, the DOE-EM's strategic goal for the Plumes Focus Area appears to have been structured too narrowly through the focus on short-term needs and commercialization. This structure does not provide for prioritization of problems based on the number and size of sites or the existing risk, nor on the basis of gaps in existing technology.

The following general recommendations, developed during two meetings of the Plumes Subcommittee, are intended to help DOE-EM improve technology development in the Plumes Focus Area.

Recommendation: The Plumes Focus Area should enlarge its strategic vision to fully embrace the DOE EM's strategic goals for technology development. These broader-based strategic goals are to

- decrease health and environmental risks
- decrease cost of environmental restoration
- enable restoration to proceed, and
- apply resources to the most urgent problems on a priority basis.

These strategic goals are directly applicable to the Contaminant Plumes Focus Area. Part of the challenge in implementing these goals for plume remediation is defining the problem. This problem definition requires an understanding of the

- relative health and environmental risks of the plumes
- sizes and numbers of plumes that are prime candidates for remediation
- costs of remediating the plumes
- capability of available technology to remediate the plumes, and
- prioritization to identify the most urgent problems.

Although the focus area has begun a physical, hydrogeological, and chemical inventory of the DOE plumes, it also should obtain a global view of long-term remediation needs by identifying the major risk and cost drivers associated with their remediation. Solving the technological problems presented by those DOE plumes that contribute most to total long-term risk and cost should be a major strategic goal of the Plumes Focus Area.

Recommendation: The Plumes Focus Area should (1) identify the major risk and cost drivers associated with remediation of DOE contaminant plumes and (2) develop an integrated systems approach to drive technology development that meets the EM strategic goals of risk reduction, cost efficiency, and environmental restoration.

The strategic goal recorded in the *Environmental Management Strategic Plan* (USDOE, 1994) highlights the optimistic goal of reducing plume characterization expenditures by 50 percent by fiscal year 1997. An integrated systems approach might enable DOE to achieve such a cost reduction while still obtaining sufficient characterization data. This goal of reducing characterization expenses also might help meet the overall DOE-EM goals. This recommendation is especially important because numerous contaminant plumes still have not been characterized adequately.

Recommendation: Appropriate internal and external peer reviews of the characterization efforts should be conducted and should become a fundamental part of this integrated systems approach (see Chapter 2, p. 13).

Recommendation: A continuing integrated effort of EM-50 with EM-30 and EM-40 is needed for the Plumes Focus Area to achieve its remediation goals. Also, EM-50 should bring into its technology-development planning some external groups of expertise, including industry and academia, for guidance purposes. Expert or external advisory panels could fill this need.

Although the Plumes Focus Area is working with various stakeholders (from industry, academia, the national laboratories, and other federal agencies) to identify technology needs and to develop technologies, these efforts are not well integrated and often lose focus on the end objective. The intent of this recommendation is to encourage DOE to collaborate more fully with external experts who have a strong interest in achieving such objectives. One particular EM-50 program that has helped to leverage research in this way is the LASAGNA™[6] technology project discussed in the next section. DOE is encouraged to form additional teams of this type to integrate their remediation efforts, both internally and externally.

In-Situ Remediation of TCE — A Productive Industry/DOE/EPA Demonstration Using LASAGNATM

Contamination in low-permeability soils poses a significant technical challenge to in-situ remediation. One demonstrated solution to this problem combines electro-osmosis with treatment zones established in the contaminated soils.

The contaminant targeted in an initial field demonstration was trichlorethylene (TCE) at the DOE Gaseous Diffusion Plant in Paducah, Kentucky. The demonstration utilized a process called LASAGNA™. The consortium, known as the Remediation Technology Development Forum (RTDF), which was coordinated by Monsanto, consisted of DuPont and General Electric with participation from the DOE and the EPA. The program was facilitated by Clean Sites, Inc. and implemented by CDM Federal.

Applications and benefits claimed for this process are

- treatment of organic and inorganic contamination, as well as mixed wastes;
- greatly reduced environmental impacts;
- increased cost effectiveness;
- minimal waste generation;
- increased treatment flexibility; and
- broad application for a wide range of sites and contaminants.

Other attributes of this process are rapid technology development and royalty-free use of technology. The Phase I demonstration, completed in the summer of 1995, met and exceeded all expectations for quantitative (mass balance) removal of TCE. Phase II, now in preparation, will involve scale-up and remediation of the Paducah Site.

Recommendation: An assessment of what has been accomplished and learned so far by the Plumes Focus Area is necessary. Each remediation or demonstration should be evaluated to identify successes and lessons learned addressing the questions of what it did and did not accomplish, and why. These lessons learned could be

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[6] The LASAGNA™ technology, a trademark of the Monsanto Company, is a system or combination of components in a configuration of electrodes and degradation zones that permits in-situ treatment of contaminants in low-permeability environments. Monsanto Company has coined the word LASAGNA to identify its products and services based on this integrated in-situ remediation technology.

valuable scientific data in charting progress and learning about remediation attempts and could serve as a guide for a future approach. It is important to look at all learning experiences as well as successes, because these experiences have valuable information content. Eventually, good rationale for technology development could be developed, ideally based on both field data and theoretical models.

Cleanup Objectives

Cleanup goals are an integral part of evaluation of appropriate technologies, remediation costs, and even feasibility of remediation. Goals often are set by regulations and typically are defined in terms of concentration of contaminants in the ground water or soil after remediation is complete. However, such cleanup goals can be elusive if the technical capabilities of existing and emerging technologies are not considered. For example, for most sites with complex hydrogeology and chemistry, attainment of current drinking-water standards generally is not possible with conventional technologies nor has it been demonstrated adequately with emerging technologies. The limitations of existing technologies, the implications of current cleanup standards, and alternative approaches to setting cleanup goals were discussed in *Alternatives to Ground Water Cleanup* (NRC, 1994). Risk-based goals, that result in site-specific cleanup goals, are alternatives that are receiving consideration by many agencies throughout the country. Technical impracticability issues also must be considered.

Recommendation: DOE should establish a process for developing specific cleanup goals for each of its contaminated sites, because the appropriate approach for remediation of a site depends upon the cleanup goals, intended land use, and technical practicality issues.

Recommendation: DOE should compile an inventory of the scope (size and type) of contaminant plumes including thorough documentation and quantitative evaluations of risk and costs posed by these plumes. Major technological needs to address high-risk and cost sites should be identified in this process. It is important to stress that setting priorities rationally is not possible until a problem is defined.

Criteria

The selection of end points in remediation is integral to technology development. How much technology development is done (characterization, containment, and remediation) depends on the criteria or end points that are established.

The use of relevant criteria by which to characterize, contain, and remediate contaminant plumes, and the uses of risk and cost trade-offs were addressed by the subcommittee. During briefings, EM-50 indicated that their technology-development strategy is based on a three-step approach: containment of the biggest contaminant risks, treatment of ground water, and then treatment of soil contamination (which is considered a longer-term threat). The Plumes Focus Area technology-development strategy is driven by matching technology to EM needs using a Decision Analysis System to guide the process. The Decision Analysis System matches available or emerging technologies from government and industry with EM site problems and demonstrates where current technologies can provide solutions and where technology gaps exist. A problem is that the sites frequently do not have the information DOE needs to help make these kinds of decisions.

Recommendation: EM-50 should complete quantification and prioritization of the contaminant plumes in the DOE complex.

Status of Current Technologies and Needs

According to EM-50 briefings, numerous technology-development/application activities are ongoing throughout the DOE complex. These efforts are organized into four areas: (1) site assessments, (2) contaminant characterization, (3) treatment technologies, and (4) containment technology. Methods for measuring aquifer properties, on-line remediation process controls, and subsurface exploration and access tools are under development to improve site-assessment approaches. Closely associated with these efforts are programs to characterize DNAPLs and other contaminants using noninvasive techniques. In addition, significant efforts are being directed toward identification of in-situ treatment of plumes to minimize worker and public exposure, waste generation, and costs. Coupled with the in-situ treatment technology focus are efforts to implement effective, reactive barriers for containment of the plumes. In addition, EM-50 is evaluating technologies that have application across three key research areas, such as robotics technology; characterization, monitoring, and sensor technology; and separations technology.

Although these areas of technology development are numerous and are being pursued with great vigor and energy, the Contaminant Plume Subcommittee presently is not able to judge the appropriateness or progress of the program without additional information. This needed information consists of quantification and prioritization of the contaminant plumes in the DOE complex. Once this information is assembled, a more realistic assessment can be made regarding the effectiveness, appropriateness, and timeliness of current research activities, as well as major technology needs in the Plumes Focus Area.

Recommendation: Tools to locate DNAPLs, as well as in-situ sensors to reduce burdensome laboratory costs, should be developed and/or refined. These efforts must be coordinated with other entities (both internal and external to DOE) that are performing similar activities.

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SUBCOMMITTEE ON LANDFILLS

Overview and Summary of Preliminary Recommendations

Overview of Subcommittee Activities and Approach

Because of its brief exposure to DOE landfill technology-development efforts during its two meetings in 1995, the subcommittee feels that both its findings and recommendations must be considered preliminary. In addition, the subcommittee accepted as its charge for 1995 to make only constructive recommendations that can be implemented by the Landfills Focus Area in the short term. Preliminary observations and recommendations presented in this overview and summary have been selected from the body of this report, which contains the rationale and more detailed discussion of each observation and recommendation.

Observations and Preliminary Recommendations

1. Reorganization of DOE technology development into focus areas is a positive development. The Landfills Focus Area has moved aggressively to implement departmental guidance, and there is clear evidence that initial efforts have been successful. The focus area technical team demonstrates a high-level of *esprit de corps* and willingness to engage in cooperative R&D between laboratories and sites.
2. Greater effort in long-term performance testing and monitoring of engineered containment techniques and systems, including covers, caps, barrier walls, and floors, is encouraged.
3. If the Landfills Focus Area receives adequate and stable funding, it is probable that DOE will be able to meet its needs to develop better technology.
4. A problem-solving orientation in technology development is advocated.
5. A ranking/categorization for landfill-related problems based on relative risk would be useful to drive technology development in DOE. These analyses need not use sophisticated models and may already exist to some degree in DOE literature. Technology needs determined by this risk prioritization process would establish technical tasks. These technical tasks would then be organized into technology-based

product lines, rather than the waste-type and climate-based product lines as they are organized currently. The proposed technology grouping would include five product lines:

(1) characterization,
(2) retrieval,
(3) treatment (including both in-and ex-situ methods),
(4) containment and monitoring, and
(5) systems integration and design.

6. The technology-development program in the Landfills Focus Area would benefit greatly from a critical ongoing assessment of the efficacy and efficiency of technologies already developed both inside and outside DOE. Recent work in assessing the state-of-the-art in relevant technical areas addressing DOE's priority needs is supported, and an increased level of effort in this area is needed. The desired goal is to establish DOE's niche in environmental technology development by focusing DOE-EM's efforts in technology development into areas of need not well supported outside of the department.
7. Each technical project would benefit from clearly established goals and a strategic plan to guide development. An action plan describing how strategic goals are to be met should be part of an assessment of field applications. The subcommittee is strongly supportive of "gate" reviews and believes that the gate-review concept would be helpful in R&D planning (see discussion of gate reviews in Chapter 3, page 19).
8. The Landfills Focus Area should be proactive in working with regulatory agencies to establish criteria that will promote regulatory acceptance of appropriate landfill remediation technologies. Also, agreed-upon means for establishing targeted cleanup levels would serve as useful guides to technology-development activities. The subcommittee does not challenge the notion that cleanup levels should be site specific.
9. Increased effort in performing project peer reviews (for example, the EM-50 Project Review [TTP No. SF201101] of In-Situ Microbial Filter Project by the Plumes Focus Area, June 6-7, 1995) by external technical experts who have been rigorously screened for conflict of interest is strongly encouraged. Such peer review could take place at a particular "gate" of the DOE-EM technology maturation model, or at highly focused workshops where related technology projects are assessed.

Preliminary Findings, Observations, and Recommendations

Scope of DOE Landfills Focus Area

The Landfills Focus Area has defined its scope as that of technology development appropriate for DOE landfill needs. Improvements in technical methods are sought in each aspect of remediation. The stages of remediation include assessment (or characterization of both sites and buried waste), selection of one or more treatment options, design of the remediation system, implementation of the remediation plan, and post-monitoring (as appropriate) to confirm risk abatement. Remediation options for landfills include

- excavation (or retrieval), with the generation of a waste stream destined for above-ground storage and/or ex-situ treatment;
- containment, as with barriers;
- in-situ stabilization, as with an injected grout or in-situ vitrification; and
- in-situ remediation, using physical, chemical, and/or biological techniques.

Because of the magnitude and variety of DOE landfill problems (with an estimated three million cubic meters of buried waste in landfills nationwide, in a variety of climates and hydrogeological settings), it is anticipated that each of the above-mentioned remediation options will find application somewhere in the DOE complex. The Landfills Focus Area, with an annual budget between $30 and $50 million, has supported work in Fiscal Years (FY) 1995 and 1996 in the areas of assessment, retrieval, containment, in-situ stabilization, in-situ remediation, and ex-situ treatment.

Overview of DOE Landfills Program and Focus Area

The Landfills Focus Area has begun an ambitious program of facilitating technology development. Several clearly defined roles or program elements can be identified.

1. *The focus area awards funding to R&D projects that have technical merit and contribute to program goals.* For organizational purposes, these projects have been grouped into four areas, called product lines, each overseen and coordinated by a separate program manager.
2. *Based on strategic plans developed within DOE-EM, the Landfills Focus Area has undertaken strategic planning activity* (USDOE, 1994).
3. *Assessment of state-of-the-art practices in relevant technical areas.* Examples of information gathering activities include the *International Containment Technology Workshop* (August 29-31, 1995, in Baltimore, Md.), the *TRU (transuranic), TRU Mixed, and Mixed Low-Level Waste Treatment Technologies Technical Peer Review* meeting (November 13-15, 1995, in Dallas, Tex.), and the *Non-Destructive Assay and Non-Destructive Evaluation (NDA/NDE)* workshop (January 25-26, 1996, in Pittsburgh, Pa.). Another example is the technical "bakeoff" demonstrations, such as the Very Early Time ElectroMagnetic (VETEM) demonstration planned at Idaho National Engineering Laboratory (INEL), where

competing technical methods and systems can be compared by their performance on a common test bed.

4. *Interaction with technology customers within DOE.* Interactions with stakeholders and EM-40 site managers have occurred through the Site Technology Coordination Groups (STCGs) and through the efforts of the External Integration Team. An end user is required of all projects funded beyond "gate four" of the R&D technology maturation model developed within EM-50.
5. *Interactions of the focus area's industrial team with commercial and industrial organizations to assess what to buy outside of DOE versus what to develop in-house.* This work includes market assessment and the development of commercialization or business plans for DOE-developed technologies.
6. *Performance of technology demonstrations on DOE sites.* Interaction with technology developers and a site selection process are involved.

The Subcommittee on Landfills endorses the new approach to DOE technology development begun in 1994 with formation of the focus area structure, and the work of the Landfills Focus Area in their efforts to implement this new approach.

Strategic Planning, Programmatic Goals, and Performance Measures

A problem-solving orientation for technology development is advocated. The development, demonstration, and implementation of environmental remediation technologies should be focused on the problems of the DOE sites. Implementing a problem-oriented technology-development plan encompasses the following:

- problem identification and prioritization;
- identification of the technology needs to control, eliminate, and/or minimize the risk that established the problem;
- establishment of goals tied to a strategic plan to track technical progress toward problem solution; and
- restructuring of the organizational product lines to focus on problem solving, with the establishment of an additional Systems Integration and Design Group.

A problem-solving orientation requires that the problems be ranked according to risk, forcing the earliest attention on the problems whose solutions yield the greatest benefit. It also avoids the criticism that the easiest, least important problems are the first ones examined and solved. However, the time required to solve the problem also should be considered when determining technologies appropriate for the solution. Ranking the problems according to risk requires the definition of risk, the human or environmental component at risk, and the time frames of concern for the risk. For example, the risk measure may be 100 mrem/yr to critical members of the population after 300 years of site control. The risk measure also may be inferred by indirect criteria such as the drinking-water limiting concentrations to potential potable water sources off-site.

The data needed for a risk determination may not be available, highlighting the need for proper characterization of each problem, particularly the inventory and contaminant characteristics. However, sufficient data on the critical parameters should be available for a preliminary evaluation of risk sufficient for ranking. A complete characterization is not required to evaluate reasonably the risk ranking for landfills.

The next step involves determining the contaminant inventory and characteristics, the potential pathways for contact, and the critical pathways for the potential exposures. These pathways then must be characterized, and the appropriate models for the risk must be selected. The model need not be sophisticated for the purpose of ranking the problems.

Regulatory Aspects Impacting the Landfills Focus Area

One way to view landfill-remediation needs is to understand the regulatory requirements for legal closure at a landfill site. Any existing or potential releases of hazardous chemicals and/or radioactive waste to the environment makes a site eligible for consideration in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)/Superfund Amendments and Reauthorization Act (1986) (SARA) process, among other Applicable or Relevant and Appropriate Requirements, (ARARs).

These ARARs, including CERCLA/SARA legislation, allow for Removal Actions. Where there is a threat to public health or welfare or the environment, Removal Actions, whether Time or Non-Time Critical, can be implemented. Removal Actions shall, to the extent practical, contribute to the efficient performance of the anticipated long-term remedial action. For some landfills of interest here, this categorization is possible and currently is practiced by another federal agency (the Department of Defense) to expedite site remediation.

If Removal Actions are not appropriate, the full CERCLA process on a relevant Operable Unit is then invoked, involving a period of investigation that results in a Remedial Investigation/Feasibility Study (RI/FS), followed by the signed Record of Decision (ROD), containing the legally agreed upon remediation method.

Flexibility is built into some RODs, allowing attempts at alternate solutions for trial periods typically lasting approximately one year (see, for example, Soelberg et al., 1995). However, the schedule of ROD signings dictates the end of the period during which various remediation scenarios are debated most fully. The use of a new technical method would have to be advocated prior to the ROD signing. The bulk of technology development is then necessary prior to the ROD. The schedule of RODs acts as a significant time constraint on the implementation and use of results of R&D work products.

For other regulatory processes, similar considerations apply. For landfills under local regulation, a new technology advocated for use would have to gain acceptance by local regulators. Those technical methods that have achieved a greater level of maturity, testing, and history of successful application would naturally be favored.

Recommendations

1. The Landfills Focus Area should be proactive in working with regulators on landfill remediation. Consultations to date with the EPA are supported, and it is hoped that such continued interactions with representatives of regulatory agencies can produce remediation choices and designs that enjoy widespread acceptance[7].
2. Field demonstrations of appropriate technologies can enable the granting of Removal Actions and garner local regulatory support. The focus area should try to ensure that demonstrations affect this process in a positive manner. CERCLA Removal Actions are less costly than the full RI/FS process that involves more extensive characterization studies.
3. Regulatory acceptance is an important issue. A regulator or regulatory body's yes/no (go/no go) decision to try an emerging remediation technique can translate directly into the worthiness of the requisite technology development. In general, only technologies at a sufficiently mature level of development will be able to undergo a credible field test demonstration and be considered seriously for regulatory approval. Because this maturity occurs at the end of development, the development costs are undertaken with some risk. Regulators have been described as reluctant to participate in technology development, or to endorse a technical method, prior to its full development, and such caution is understandable. Technology developers can be frustrated not knowing whether technical progress will translate into the regulatory acceptance required for deployment. Technology seminars with state and local regulators would help expand their knowledge of the applicability of new and existing remedial technologies. Presenters at these seminars should include experts from within as well as outside DOE.

The straightforward answer to this situation is to have technical *criteria* established that serve both state and local regulators. The Landfills Focus Area should establish criteria that satisfy the relevant regulations and serve as guidelines for technology development. To help facilitate interactions of the focus area with regulators and developers, the focus area should disseminate the criteria broadly, especially within DOE, EPA, and state regulatory agencies.

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[7] Briefings to the Subcommittee on Landfills by DOE-EM 50 personnel and Subijoy Dutta of the U. S. EPA

Status of Current DOE Environmental-Technology Projects

The Digface characterization project being developed by the Idaho National Engineering Laboratory (INEL), Ecology International, and Rust Geotech Inc., is an integrated demonstration of multiple sensors that can be used as part of a retrieval effort. The Digface characterization technology will allow continuous and continually improving monitoring and characterization of the site being remediated. The Digface characterization excavation system is useful and fills a needed role of providing characterization information beyond the limitations of present nonintrusive techniques. (For a list of FY 1995 projects, see USDOE [1995 a, b]).

The issue here is the adequacy of existing information (from historical records and from characterization studies done with current methods) in providing a sufficient waste and site assessment for remediation planning purposes. The question is raised whether present technical methods can supply this information adequately, without costly drilling and sampling. An example of a significant omission with present techniques is an underground storage tank at Fernald that was not discovered during site characterization; its later discovery required adjustments to the remediation strategy. The Digface system seems to provide a technical approach to proceed with available information, and with the flexibility to acquire more information and make decisions as the excavation proceeds.

The projects cited below are examples of work whose rationale for development does not seem to be on a sufficiently firm basis to be treated as priorities. Items 1, 2, 4, and 6 are developed technologies and item 3 has a doubtful success probability in the short (2–5 years) term. Success is needed for containment in situ, which should remain a development priority along with monitoring methods. Item 5 is a temporary fix in an arid environment. The short-term benefit from air drying of a coarse-grained cover layer does not outweigh the cost of the technology.

1. *Alternative Landfill Cover Demonstration (LLW/Arid).* The proposed project area generally is considered to be a developed technology, and facilities currently are using the ideas. One example is the radon barrier and cover field test at Grand Junction, Colorado, multiyear field test conducted over several years. Another example is the multilayer earthen cover system planned for the Low-Level Waste Disposal Facility in North Carolina.

   Although the program is currently conducted in an arid environment, it should take place in a humid environment, which is the more critical use for multilayer covers.

   This project also needs mass balance data (supporting a relation such as In(precipitation) = Out(evapotranspiration + capture/collection) at an appropriate site to evaluate effectiveness.
2. *Design of Capillary Barriers (LLW/Arid).* This project area is well developed, including computer codes to predict capillary performance. Capillary barriers are being used in covers, and they have also been designed and proposed in covers over

commercial LLW disposal facilities. An example is the multilayer earthen cover system planned for the California Low-Level Waste Disposal System. It has a capillary barrier that also functions as a biointrusion barrier. Again, the capillary barrier program should be conducted in a humid environment.

3. *Subsurface Barrier Emplacement (Grouts) (LLW/Arid; LLW/Non-Arid).* DOE sites have worked on this project area for decades. In-situ grouting has met with limited success and is not used commercially because integral barriers have not been achieved. It is also difficult to determine in the short run if a grout barrier under a landfill maintains full integrity. Short-run success is doubtful for this area. The technology is not in the technology-development stage, but is in the research stage. Better testing methods to evaluate barrier performance are also needed.
4. *Radon Mitigation and Monitoring at Fernald.* Techniques have been developed for mitigation and monitoring of radon in the environment. This project sounds more like a site application test than a technology-development test.
5. *Dry Barriers for Covers (LLW/Arid).* This project may reduce moisture in earth covers in arid environments. However, it is an active process that is a temporary solution at best.
6. *Tracers to Determine Transport Processes in the Vadose Zone.* Tracers have been used to determine water and gaseous flow in geologic media for several years. Most geohydrologists believe that transport processes are well understood but are not easy to monitor quantitatively. Field experience, modeling, and testing of vadose zone transport have established a suitable technical basis for design and implementation.
7. *Thermal Enhanced Soil Vapor Extraction.* This technique has been demonstrated (Cox et al., 1995; Gopinath and Germar, 1995; Strzempka et al., 1995) commercially using more cost-effective methods than DOE's electrode-type heating probes.

State-of-the-Art Assessment of Environmental Technologies

The Landfills Focus Area should identify clearly those technologies needed to address specific site-related problems, including an assessment of the state-of-the-art technologies that have found application to similar problems both inside and outside of DOE. This assessment involves locating and referencing relevant resources and centers of expertise, with a goal of establishing the unique niche or role of DOE in technology development.

Projects included in the 1995 technology-development program (USDOE, 1995a) focus on the demonstration of a wide variety of technologies, not all of which are uniquely attributable to DOE research and development. Indeed, DOE has not played a significant role in the development of some of the technologies counted as "successes" or work products. In other instances, technology development has not been clearly focused on the technology needs for solving specific problems. Past program plans sometimes have neglected critical assessment of state-of-knowledge in project-related areas and do not show evidence of leveraging DOE efforts with existing centers of expertise. Specifically, DOE technology-program plans do not establish clearly DOE's niche in contributing to the development of those technologies that are already the subject of broad-based research and development efforts elsewhere.

Implementing technology demonstrations is a significant part of the Landfills Focus Area activity, and such demonstrations need not necessarily come from in-house development. In briefings to the subcommittee at the Savannah River Laboratory, the FY 1996 program for technology development in the Plumes and Landfills focus areas demonstrated greater knowledge and outreach. It is hoped that a technology-based focus area approach for problem solution will help foster further development of the context in which the DOE technology program exists.

To this end, the focus area should engage in outreach activities that seek out the best in each technical field. One aim of this effort is to provide the rationale for the technology-development activity that is sponsored within the agency. Another aim is to engage peer review input.

DOE headquarters has made efforts to work with other agencies and private sector vendors, such as the recent co-sponsoring of the August 1995 *International Containment Technology Workshop* in Baltimore, Md., by DOE, EPA, and DuPont (USDOE et al., 1996). The invited speakers included representatives from abroad and from a host of institutions, including industry, the USNRC, and universities. This effort of soliciting broad-based input for technical issues in barrier technology is the kind of activity required to develop the rationale for the DOE program in barriers. Input on state-of-the-art practice, a sense of technical needs, and ideas for what methods are most suitable for deployment in DOE are the kinds of information that are needed to establish an understanding of the technical-development program. Specifically, the policy-related findings of this workshop should be established and recorded. The plan to convene a more rigorous follow-up public conference in the near future (early 1997) is supported.

Similar information-seeking efforts conducted by the Landfills Focus Area in late 1995 also are supported. These include the transuranic (*TRU), TRU Mixed, and Mixed Low-Level Waste Treatment Technology Technical Peer Review* meeting (November 13-15, 1995, in Dallas, Tex.), the *Non-Destructive Assay and Non-Destructive Evaluation* workshop *(NDA/NDE)* (January 25-26, 1996, in Pittsburgh, Pa.), and the Very Early Time Electromagnetic (VETEM) technical demonstration (scheduled for late 1995 at INEL). This approach for key technical areas of importance in landfill remediation strategy is endorsed.

A key decision emerging from this process is the determination of the technical areas in which DOE wants to have in-house, first-rate expertise. This process involves deselecting some technical areas in ER where external expertise can then be called in, perhaps in a subcontractor role, and in which DOE can view itself as a customer.

Barrier and Cap Technology

The integrity and long-term performance of cap and barrier walls are issues worthy of further work that is focused in certain areas of need. These issues are discussed below. Although caps can be successful (as shown by archaeological analogs in burial mounds) present designs have exhibited shortcomings, mainly through biointrusion of both animals and plants. However, little is known at present about long-term performance of presently engineered barrier walls and caps. Arguably, the most long-term data on present cap design are on vegetated caps, installed in the mid-1980's (Schulz et al., 1995); the DOE Hanford Site Permanent Isolation Surface Barrier work (Cadwell et al., 1993); and the DOE Uranium Mill Tailings Remedial Action Program (UMTRAP) work (Zellmer, 1981; Simmons and Gee, 1981; Gee et al., 1984; Mayer et al., 1981a; Cline et al., 1982; Voorhees et al., 1983; Beedlow, 1984; and Mayer et al., 1981b) done in the late 1970's and early 1980's. The subcommittee heard from several researchers and practitioners that long-term data on barrier wall performance are also a significant need[8] (USDOE et al., 1996; ER'95, in press). To collect such data, a limited program of long-term performance assessment of barrier walls and caps is recommended, because these are key components of present DOE Environmental Restoration (ER) strategy[9]. It can be argued that every barrier wall, or a representative sample of them, should be monitored over the design lifetime.

A program for monitoring long-term performance is suggested, in part because of current limitations of verification and monitoring techniques (Heiser, 1994). For an example of a testing and monitoring plan, see Gee et al. (1993). The work should not repeat previous studies of this type; rather it should have a clear objective with specific outcomes, and it should be focused on humid, not arid sites.

The reason for such a monitoring effort is that caps and barrier walls are not a proven permanent isolation technique. Their failure depends upon imperfections and nonidealities in installation and on material properties. For a discussion of failure mechanisms and construction quality assurance and control, see Rumer and Ryan (1995). The subcommittee has heard from practitioners that present field installation methods make guaranteeing integrity difficult. Pathways for leaks can be produced by mechanical stresses at interfaces, during installation or due to underlying strata. Present materials (grout, slurry, and plastics) possess finite leachability and conductivity parameters that do not guarantee long-term environmental isolation.

One suggestion is to perform field studies on existing DOE-UMTRAP caps, which were designed to last 1000 years, in compliance with regulations. The Cannonsburg, Pa., site is a candidate for humid-area studies.

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[8] Briefing to the Subcommittee on Landfills by Professor David Daniel of the University of Texas at Austin, July 20, 1995, Washington, D.C.

[9] Remarks of John Lehr at *Barriers for Long-Term Isolation Workshop* , on in-place actions envisioned within the Office of Environmental Restoration (EM-40) throughout the DOE-EM complex; ER'95, 1996.

Technical-Needs Assessment Studies

An ongoing and more extensive system of needs assessment is encouraged. Part of this assessment involves dialogue with EM-40 customers, which the focus area has begun and which should continue. Another component of this assessment involves a comparison between the results of expected environmental transport mechanisms (including the ultimate fate of the contaminants) and the proposed plans to assess the long-term adequacy of the proposed remediation methods. Such comparisons also should be continued. One way to do this is to compare two technical studies. The first is a study to assess the leachability of materials in present DOE landfills, and the methods used to assess long-term leachability characteristics. This work would be useful for establishing DOE "waste acceptance criteria" for future waste designated for landfill disposal. Long-term leachability characterization also should assess differing climate conditions.

The second is a study (see, for example, Siskind and Heiser, 1993; Heiser and Milian, 1994) to assess the materials used in stabilization and containment methods. Such a study should include information on hydraulic conductivity, permeability, long-term integrity, and application considerations under varying source conditions. Work that tracks the progress of technical work in this area can be used as a reference to establish DOE criteria for selecting both the material and the method of application.

The results of these two studies should establish knowledgeable estimates on the relevant time scale and degree of containment achieved by containment and stabilization methods.

Performance Measure Modification

Program performance measures (USDOE, 1994), a management tool designed to facilitate a problem-solving approach, should be modified as necessary to measure factors that reflect desirable working relationships. Specifically, a record should be kept of the number of challenging technical and environmental problems that are solved, and such a count should be given greater weight in assessing the program than the presently used performance measures for EM-40 and EM-50. Higher-risk problems should be given correspondingly higher weighting factors.

General Guidance and Subcommittee Perspective

The preliminary recommendations outlined above have been given with the intention of

- retaining the practice of sound environmental science and technology in DOE's landfill remediation work,
- establishing implementation techniques that provide long-term protection, and
- developing methods to monitor the long-term effectiveness of landfills, to the extent possible.

To guide its work in technology development, DOE's program should interact with, draw from, and support the best of research and application activity in appropriate disciplines.

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SUBCOMMITTEE ON HIGH-LEVEL WASTE IN TANKS

Introduction

The Subcommittee on High-Level Waste in Tanks was formed in the second half of 1995 and has held two meetings. On the basis of the information obtained during those meetings and coupled with the experience of the members, this report is a preliminary assessment of the issues pertaining to technology needs for the disposition of radioactive waste in tanks. The approach was to comment on the technology issues and needs relative to the current approaches being taken for remediation of the tank wastes by DOE and its contractors. Prior to discussing technology needs, a limited amount of background information is provided based principally on *Radioactive Tank Waste Remediation Focus Area* (USDOE, 1995a).

The high-level waste tank issue has to do with the safe management of over 100 million gallons of radioactive wastes in 332 underground storage tanks distributed among five sites. The five sites are Hanford, Savannah River, the Idaho National Engineering Laboratory (INEL), Oak Ridge National Laboratory (ORNL), and West Valley, New York. Of the 332 tanks across the complex, 177 are located at Hanford, which contain over 60 percent of the DOE tank waste (USDOE, 1995b).

The waste in the 332 tanks is in the form of sludge, supernate, and saltcake. The wastes at the five sites differ in quantity, age, storage mode, originating process, chemical composition, and physical attribute. In most of the tanks, the wastes, originally formed as acidic solutions of radioactive nuclides, are now in a strong basic medium and hence have various solids associated with the caustic supernate. In addition, some sites have processed some of the wastes to concentrate the solutions and reduce the volumes, resulting in crystallized components of the waste also being present in tanks. Finally, some of the wastes were formed during processing of the original source of waste to remove selected components by processes that differ from those that formed the waste. In short, wastes in the tanks are a heterogeneous mixture of solutions, sludges, saltcakes, and other phases.

Some of the tanks have leaked, and the ability of a significant but unknown number of tanks to confine the liquid phases has been lost. Further, some of the tanks have generated combustible gases leading to the potential of conflagrations or explosions. The current practice at all sites is to manage the safety issues on a high-priority basis. Processing for the final disposition of the contents of the tanks is being implemented at only two of the sites, the Savannah River Site/ Defense Waste Processing facility (SRS/DWPF), and the West Valley Demonstration Project (WVDP)[10]. It is likely that at all of the sites, several types of actions using existing technologies will take place as discussed in the next section and highlighted in Figure 1. The report focuses on the identification of those technology needs that appear to be pertinent, generally, to the five sites currently holding such waste. These sites, i.e., Hanford, Savannah River, West Valley, Oak Ridge, and the Idaho Chemical Processing Plant (ICPP) are in various stages of developing processes and facilities for the conversion of waste in tanks to stable forms of high-level waste (HLW) and low-level waste (LLW)[11] (Westinghouse Savannah River Company, 1994; Priebe and Valentine, 1980; Gephart and Lundgren, 1995; INEL, 1994).

Technology pertinent to the management of the waste in tanks will include all processes, operations, and facilities used in the conversion of material in the tanks to the desired end products, including disposal of the tanks. The subcommittee has not been provided with, nor has it obtained a comprehensive catalog of the current activities of the various departments of the DOE that are pursuing the development of technologies related to the management of wastes in tanks. The subcommittee has obtained information on parts of some of the programs pertinent to waste in tanks, and members of the subcommittee have had access to information related to such activities. Nevertheless, this report should be considered preliminary. Finally, this report will not include details of technologies pertinent to the management of waste in tanks, but rather will address the general issues posed by these wastes and the planned management strategies. Future reports of the subcommittee will reach beyond the "planned" strategies and take a scenario approach to identifying technology needs. This approach is briefly discussed in the following section.

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[10] With respect to the Defense Waste Processing Facility, some safety aspects are not yet fully resolved in all the steps of the process. The result is that "hot" startup has been postponed until approximately March 1996. With respect to West Valley, following a leak in the melter, a review team identified the need for several improvements in the operation of the process equipment. Operations have been delayed until all improvements are implemented.

[11] In some cases, these designations may not be entirely appropriate but are used here to designate waste that is highly radioactive and hazardous (HLW) and waste that is much less radioactive and generally much less hazardous (LLW). Since there is not now an accepted definition of such wastes based on their hazard, the definitions of HLW and LLW currently in use will be maintained.

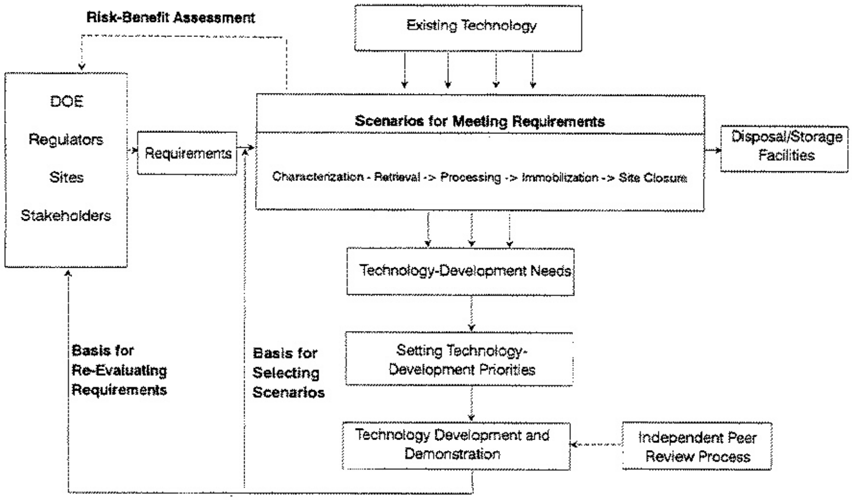

Figure 1:
Relationship of Technology Development to Waste Remediation

Scenario Approach

It is the subcommittee's intention to emphasize what the scenario evaluations indicate as the overarching needs and issues that directly affect many components of technology development and indirectly affect all aspects of tank waste remediation. The subcommittee chooses a scenario strategy (i.e., how the subcommittee will conduct its investigations, not DOE strategy) as the best way to address overall technology issues and needs. The subcommittee will seek to distinguish between site-specific issues and issues applicable to multiple sites.

Figure 1 is an attempt to diagram the relationship of technology development to the disposition of radioactive waste in tanks. The figure is very conceptual and is not an attempt to depict the details of what actually happens. Furthermore, some of the steps are yet to be defined, such as the peer-review process and the use of risk-benefit methods to prioritize the scenarios. For the case of high-level waste in tanks, the range of scenarios and end states might vary from the "no-action" scenario (perpetual surveillance and maintenance), and containment-in-place scenario (stabilize tank contents and tank forms), to scenarios that would lead to vitrified waste for disposal and a pristine site. Of course, all the in-between states involve different degrees of clean up. Except for the "in-place" scenarios, the sequence of events comprising the scenarios would consist of such activities as waste characterization, retrieval from the tanks, processing, immobilization, site closure, with differing technology-development needs. The result would be a clear display of the technologies involved, including those that are developed and available as well as those needing development. The task then becomes one of assessing the scenarios against the chosen set of performance measures leading to the identification of technology-development requirements. Candidate performance measures are safety of the workers and public, cost and schedule, public acceptance, environmental and economic impact, and technical feasibility. Prioritizing a scenario at this early stage will most likely be done against a much smaller set of performance measures such as safety and regulatory acceptability.

Common Technology Needs

Evaluation of the presentations made and DOE documents led to the conclusion that there are significant common technology-development needs related to the management of high-level waste in tanks. These needs are listed in Table 1 and are preliminarily ordered in decreasing order of importance.

TABLE 1: Technology-Development Needs for Managing High-Level Waste in Tanks that are Common to All Sites[12]

- Waste characterization.
- Final disposition of tanks containing residual waste.
- Retrieval of multiphase wastes from tanks with access limitations.
- Vitrification of wastes, including off gas treatment and recycle of volatile radionuclides.
- Removal of Cs from supernatant, dissolved solids, and secondary wastes.
- Disposition of used melters.

Both Savannah River and West Valley have progressed in the development of processes and facilities for the treatment of wastes in tanks. Both sites plan to produce HLW glass and process the associated LLW wastes into grout during 1996. For these

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[12] The commonality of these needs to the Idaho site may be limited because of significant differences in the nature of the waste and the proposed management approach (i.e., acid dissolution).

operations, the technology needs will focus on the final steps of the remediation process, namely the final disposition of the tanks and the residual waste in them. The subcommittee could not determine criteria from any site for the allowed residual waste in tanks or a general outline of plans for the final disposition of the tanks themselves after the remediation process. There could be significant technology-development needs when such decisions are made, because it is likely that complete removal of waste from the tanks is impractical and confinement of residue in the tanks for prolonged periods will be a requirement. Further, if complete removal of the tanks becomes a requirement, it is clear that considerable development and testing of techniques will be required.

All of the sites have elected to produce a form of glass as the waste form for HLW. While the details of melter design, size, operation, expected life, and maintenance may be different among the sites, in all cases the melter off gas system will be an important part of the process. The subcommittee believes that technology to recycle the expected volatile components of the melter feed, with particular attention to some of the radioactive materials in that feed, will need to be developed and tested. Further, the disposition of massive highly radioactive melters that are no longer functional or have been subjected to unplanned incidents may require technologies that are not yet available and will need to be developed.

Due to the differences in the compositions of the wastes, processes to effect required separations may be somewhat different among the sites. However, removal of multiphase waste from tanks in various states of disrepair will be an activity at all sites. While both Savannah River and West Valley apparently have produced satisfactory waste removal systems, such is not the case for Hanford and Oak Ridge. The waste at Hanford appears to be particularly recalcitrant in that aged sludge, saltcake, and supernate solution may be present in a single tank. The subcommittee concludes that techniques for the retrieval of tank contents, especially in light of the potential for many single-shell tanks to have leaks of radioactive liquids, are a common technology need.

The common needs listed in Table 1 are directed primarily at the four DOE sites that have alkaline nitrate supernatant-salt-sludge wastes in tanks. While technology developed at or for one site may not be entirely applicable to the needs at another site, the subcommittee expects that there will be substantial commonalties that point to the need for an integrated technology-development program. The technology-development needs at the Idaho site will be significantly different because the wastes, the bulk of which are now present as solids, will be dissolved into acid solution as opposed to the alkaline wastes at other sites. There is significant European experience with processing and immobilizing acidic wastes that may be relevant, although the Idaho wastes are expected to have much higher sodium, aluminum, and fluoride content than those in Europe.

It is recognized that there may be other potentially common technology-development needs and that numerous site-specific technology-development needs also exist. Technology-development activities related to all of these should continue to be integrated by an entity such as the Tank Focus Area.

Specific Technology Needs

The subcommittee has not had sufficient time to evaluate site-specific technology-development programs and believes that broader issues discussed herein should take precedence. Therefore, no specific delineation of such needs will be made until the subcommittee has had a better opportunity to examine the various programs in more detail.

Major Concerns

A number of concerns that profoundly affect the technology-development efforts depicted in Figure 1 are given in Table 2. These issues are thought to be inadequately addressed relative to the needs of the technology-development program. However, the information gathered thus far is not sufficient to state this as a conclusion.

Some of the concerns (e.g., undefined end points, technology-development needs in a privatization scenario, and trade offs) in Table 2 define the boundary conditions for technology development and thus the nature and extent of technology development. The other concerns are more directly related to defining how much technology development is enough (or too much). If present approaches prevail, endpoints will be established by joint agreement among the cognizant DOE field office, the cognizant EPA, the host state, and possibly, Native American tribes. However, it is clearly within DOE's authority and ability to examine the history and trends in end points (i.e., waste-acceptance criteria) and establish moderately conservative interim end points that will provide a consistent focus for technology development.

TABLE 2: Major Concerns Affecting Development of Technology for Managing High-Level Waste in Tanks

- Performing technology development when the end points (especially waste acceptance and tank-disposition criteria) are changing or unspecified, or when unrealistic requirements are imposed.
- Technology-development needs in a privatization scenario.
- The necessity and desirability for vitrifying low-level waste.
- Accommodating top-level tradeoffs (a) between the need for technology development and cost, schedule, and performance; and (b) between the performance requirements of major process operations such as characterization and pretreatment.
- Determination of the extent to which technologies developed and validated at a particular site are applicable to other sites and wastes.
- The need to perform technology-development work using actual wastes, i.e., the relevance of work performed using simulants.

These concerns are important to the extent that (a) the subcommittee will focus on them as areas to be evaluated as it obtains data from DOE tank sites, and (b) DOE-EM should consider explicitly addressing them to provide the necessary framework for technology development.

Conclusions and Recommendations

Conclusion: Substantial technology-development needs remain to be addressed if high-level waste tanks are to be successfully remediated.

Recommendation: The DOE should continue to support a balanced technology-development program integrated across all involved organizations, including EM-30, EM-40, and EM-50, and Energy Research.

Conclusion: A relatively simple scenario-based approach to identifying and prioritizing technology-development needs is an effective and desirable method to focus technology-development efforts.

Recommendation: DOE should develop and rank tank-remediation scenarios leading to a prioritized list of technology needs as described above in those cases where it is not already doing so. The scenarios should be structured to define only the major steps from characterization through disposal or storage and to highlight only the major choices to be made. It is important that the scenarios not be presented in so much detail as to obscure the basic steps and issues.

Conclusion: There are a number of important technology needs related to managing high-level waste in tanks that are common to the four DOE sites that have alkaline nitrate supernatant-saltcake-sludge wastes. For the most part, the needs of the Idaho site are expected to be significantly different because the waste will be acidified. This indicates the need to integrate technology-development efforts through mechanisms such as focus area and cross-cutting programs, although the subcommittee has not yet had the opportunity to evaluate the effectiveness of the existing focus area.

Recommendation: An integrated technology-development program such as a focus area continues to be desirable to cost effectively develop technologies and share the results to the extent they are mutually applicable.

Conclusion: An effective technology-development program requires definition of key boundary conditions and the ability to establish how much technology development is required. A number of concerns in this regard have been identified that must be addressed to develop the technology necessary to manage high-level waste in tanks. These issues appear not to have been adressed definitively, and acceptable interim approaches have not been specified.

Recommendation: The DOE should explicitly address these concerns. Ideally, this would take the form of firm answers. More realistically, a well-conceived and consistent interim approach (e.g., use of prudently conservative waste-acceptance criteria, development of contingency technologies) should be explicitly defined.

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SUBCOMMITTEE ON MIXED WASTES

Scope and Tasks of the Subcommittee

The Committee on Environmental Management Technologies (CEMT) Subcommittee on Mixed Wastes was formed in 1995 to review the technological work of DOE, industry, and research institutions on mixed-waste management, identify the greatest needs in this focus area, and make annual recommendations to the CEMT. The subcommittee also addresses cross-cutting areas of relevance to the focus area such as robotics, efficient separation processes, and sensor technology and monitoring.

It appears that many, if not most, radioactive wastes simultaneously contain radioactive contaminants and chemically hazardous or potentially chemitoxic substances. Both groups of components are subject to restrictions to protect population as well as the environment, although rationales or bases for criteria are not necessarily identical.

For the purposes of this report, mixed wastes are defined as wastes contaminated with either transuranic elements (TRU) or low-level radioactive materials (MLLW). Sources of such waste are past and current nuclear activities (with a present inventory of at least 180,000 cubic meters) and also decontamination, cleaning, and restoration activities, such as remediation of plumes. Such wastes have to be extracted and/or collected, temporarily stored, treated, and finally disposed. The latter steps also imply general or specific characterization. The following topics will be considered in this report:

- availability of technologies in the frame of site treatment plans;
- needs for improved or new technologies;
- other drivers, such as efficiency, cost, quality of end product(s);
- impact of stakeholders.

The subcommittee will evaluate current or near-commercial technologies used or being proposed for the management of "mixed radioactive wastes"; evaluate the most promising technologies for mixed waste; consider development and implementation of technologies in the perspective of quantities, categories, location of wastes, and final disposal; suggest priorities for the development program; consider technologies in the perspective of regulatory requirements; and, where appropriate, consider non-U.S. technologies for management of mixed wastes.

Overview of the DOE Mixed-Waste Focus Area

The original strategic plans of the Mixed-Waste Focus Area (MWFA) are outlined in the *Pre-decisional Draft Strategic Plan for Technology Development* (USDOE, 1994). The stated mission of the MWFA is "to develop, demonstrate, and deliver technologies and treatment systems to treat and dispose of MLLW and MTRU in a safe, timely, and cost-effective manner" and to "be responsive to customer needs, . . . achieve compliance with regulatory requirements, and . . . achieve public acceptability." Additionally, the MWFA intends to have at least three pilot-scale demonstration systems treating actual mixed waste within three years. According to MWFA, these systems, if they are accepted for full-scale implementation, should be capable of treating 90 percent of the current MLLW inventory. The MWFA intends to accomplish its goals in seven years and then "go out of business." The more recent version of the *Program Management Plan* (USDOE, 1995) provides similar statements on mission and objectives.

One of the major considerations stated in this plan pertains to disposal of the treated mixed waste; however, no guidance or further plans for addressing this important consideration have been issued, which appears to be a serious omission in the DOE documentation. One of the most important process considerations related to disposal of mixed waste is the long-term performance of the waste form in the disposal facility.

Focusing on waste streams and needs for treatment technologies is a reasonable approach to defining and prioritizing the needs of technology development. The MWFA appears to be shifting toward this approach and should continue to do so. The focus area appears to be making progress identifying and prioritizing needs based on this waste-stream approach, and DOE's methods for prioritizing its needs for technology development based on this approach will be reviewed in the future by the Mixed-Waste Subcommittee.

The customers of the MWFA are identified as the DOE-EM Offices of Waste Management (EM-30), Environmental Restoration (EM-40), and Facility Transition (EM-60). The requirements for technology development of the DOE EM-30 are by far the most clearly defined of the three customers. Additionally, the planning documents appear to be focused toward supporting site treatment plans

(STPs), required by the Federal Facilities Compliance Act (FCCA), which is largely the responsibility of EM-30 and, to a degree, EM-40. This emphasis appears to be the correct initial emphasis for the MWFA, but the planning documents and subsequent work may benefit from more clearly defined customer needs. Such documents exist for the major nuclear DOE sites, but the degree of detail and specificity is far from uniform; the latter may illustrate the fact that conclusions cannot yet be drawn concerning technologies to be used and the evaluation of the actual problems.

The integration of DOE-EM's programs by means of focus areas involving DOE-EM headquarters, field offices, national laboratories, and other contractors is considered worthwhile by the subcommittee. A number of issues are confronting an integrated technology-development profile, such as deadlines established in legally binding negotiations, the balance between near-term and future technology-development needs, the activities being funded, issues involved in the process required by the FFCA, and strategies to decide where treatment facilities would be located to handle each category of waste stream in consonance with site consent orders. Information from EM-30 and EM-40 on how their needs are being addressed would be worthwhile to the subcommittee.

Increasing public acceptance of the technologies to be developed is a worthy goal of the MWFA and the plans under development to enhance this effort should continue.

Regulatory Aspects

Mixed waste presents unique regulatory issues because of separate and sometimes inconsistent regulations that deal with hazardous waste and radioactive components. Four primary laws that relate to management of radioactive constituents are monitored by the USNRC, the Agreement States, and DOE. However, eleven primary laws that regulate the hazardous constituents of mixed waste are implemented and controlled by a number of agencies such as the U.S. Environmental Protection Agency (EPA), state and local waste-management agencies, state or local air-quality districts, local water and sanitation districts, and federal and state offices of the Office of Safety and Health Administration (OSHA).

The Federal Facility Compliance Act (FFCA) of 1992 sets out a framework for mixed-waste management by DOE that directly affects the program and priorities of the Mixed-Waste Focus Area. The FFCA amended the Resource Conservation and Recovery Act (RCRA) and defines mixed waste broadly as waste that contains both hazardous waste and sources, special nuclear, or by-product material subject to the Atomic Energy Act of 1954. The FFCA required DOE to prepare a report containing a national inventory of mixed waste on a state-by-state basis and a report containing a national inventory of mixed-waste treatment capacities and technologies.

These reports were published by DOE in 1993 and helped set the framework for technology development for mixed-waste management. In addition to these two reports, the FFCA required DOE to devise mixed-waste plans for development of treatment capacities and technologies. These mixed-waste plans were required for each DOE facility that does not already have a state agreement. Although short planning horizons under these regulations have created a near-term impetus for selection of conventional treatment technologies, such as incineration, physical/chemical treatment, and basic separation technology, the site plans appear to provide for flexibility and do not restrict severely the application of technology that is in the development stage at this time. The status of the plan should be considered if new R&D begins on waste streams that are on schedule for treatment.

The mixed-waste plans and the inventory of technologies are intended to comply with the treatment standards of the land-disposal restrictions of RCRA. EPA has promulgated treatment standards for each of the EPA hazardous waste codes, which also identify mixed waste. The standards generally define maximum levels of hazardous constituents in the treatment residue to be landfilled based on Best Demonstrated Available Technology.

EPA is promulgating two new regulations that will have a large influence on the treatment and definition of mixed waste. First, the Hazardous Waste Identification Rule (HWIR) will attempt to define waste on a national basis by threshold concentrations of listed hazardous waste. This regulation, which may become effective in 1996, could remove significant quantities of DOE mixed waste from the RCRA regulatory scheme. Second, the EPA Combustion Strategy, also scheduled for promulgation in 1996, will affect greatly the permit requirements for thermal treatment processes such as incineration, plasma hearths and arcs, and vitrification. Technologies operating at lower temperatures could be easier to permit because they fall outside the incinerator requirements. However, these technologies may require permits under RCRA Subpart X, although most of them have not yet reached a sufficient state of development and demonstration.

In addition, the plans for DOE facilities must be approved by states with authority to prohibit land disposal of mixed waste or the EPA administrator after public participation. The involvement of the public and local regulators complicates a difficult permitting process for treatment facilities.

This permit process and public involvement are critical aspects of any environmental technology-development program. For example, the efforts of the EPA National Technical Workgroup seem to be a constructive approach. DOE should increase activities that will assist in the streamlining of the permit process. Such efforts should allow the public and regulators information, understanding, and assurance that alternative technologies have been addressed adequately. Such information would demonstrate that the most appropriate waste-treatment technology has been selected and that rigorous scientific criteria for technical effectiveness, health and safety to people and the environment, reliability, and cost are addressed during the permitting process.

Criteria for Technology Development

Two basic criteria for technology development have been identified by the MWFA in its 1994 Management Plan: (1) improve performance, reduce risks, and minimize life-cycle costs over existing technology; and (2) develop treatment capability for waste streams that cannot be treated with existing technology. These criteria appear to be appropriate for technology development for mixed-waste treatment; however, it should be noted that each of these criteria cannot be optimized individually and that tradeoffs will be required. Additionally, choosing the proper balance among these tradeoffs will necessitate both value and technical judgments. For example, reducing risks and minimizing life-cycle costs are sometimes conflicting criteria.

Technical criteria can be established to achieve the basic criteria mentioned above. For example, by identifying the waste streams for which treatment technologies currently exist and are satisfactory, the technology-development needs can be focused on the remaining waste streams. The obvious place to start is the FFCA site-treatment plans. Some of these waste streams may be amenable to treatment by existing technology with only minor modification, while other waste streams may require more important adaptation or even new technology. A systems approach that evaluates a treatment technology with respect to volume reduction, regulatory requirements, characterization efforts, and final waste-form performance should be used to identify these technology needs.

At the first level, DOE should know if technology development is to replace existing technology or if it is for a waste stream that currently has no associated treatment technology. The former assumes that a technology currently exists but has some unacceptable attributes, such as high cost, low efficiency, a narrow envelope for waste inputs, or excessive secondary waste streams. The attributes of the developing technology must clearly be better than the existing technology to warrant continued development. A careful analysis of the existing technology may shed light on opportunities for developing technology.

Because a large fraction of waste-treatment cost is for characterization, treatment technologies that can accept a wide range of waste requiring only limited waste-characterization may be more desirable than technologies requiring more detailed characterization. Of course, some minimum degree of characterization will always be required, and this baseline level could be used to benchmark the additional characterization required for potential treatment technologies under consideration.

The final waste form is another important consideration for evaluating technology development (e.g., because the radionuclide concentrations resulting from the volume reduction caused by some treatment processes may preclude disposal in a near-surface facility by failing certain waste acceptance criteria or by requiring a secondary stabilization treatment). Also, the long-term performance of the waste form in a disposal facility must be assessed, and short-term test procedures must be developed to provide indication of the waste form long-term performance. Other end points to development of individual technologies include the documentation requirements for safety and performance assessments for new technology systems. The determination that a sufficient number of treatment technologies is available to meet the DOE's mixed-waste treatment needs could serve as the end point of the program as a whole or of specific developments.

Significant progress toward focusing and prioritizing technology development along these lines has been made. However, the MWFA should also incorporate a broader systems approach in its ongoing efforts and consider factors such as volume reduction, toxicity, risk to the environment and the operators, characteristics of the end product, cost for development and operation. This broader approach will help to ensure that all important factors are considered in the selection of developing technology.

Status of Current Technologies

Waste Types and Assessment/Characterization

Waste composition dictates the range of technologies that can be applied to achieve the desired technical, regulatory, and social objectives. The MWFA encompasses over 100 waste types in five general classes: combustible organics; soils, debris, and solids; sludges; wastewater slurries and inorganics; and special wastes.

DOE has several projects designed to inspect drums for leaks and for shipment suitability, measurements of volumes, density, and radioactivity determination that will be demonstrated in the field in the next two years. The usefulness of these techniques for controlling a waste feed to a treatment technology is uncertain and must be related to the treatment technique's sensitivity to variation in feed composition and other specific factors, such as potential criticality and direct chemical hazards.

Similarly, analytical control for treatment processes, emissions monitoring, and disposal suitability of the end products are highly specific and must be addressed as part of the treatment technology. The chosen technique preferably should be automated, rugged, and reliable, and should provide as close to possible real-time analysis. An example of these needs is the flow-through alpha monitor, which detects low concentrations of alpha emitters in gas streams. This method is to be field tested in 1996.

All proposed mixed-waste treatment processes emit gaseous effluents. Emissions of volatile metals; radioactive particles; and compounds such as chlorinated dioxins and furans, products of incomplete combustion or thermal cracking under pyrolysis conditions, are a major public concern and health risk. work in the real-time analysis of these pollutants should be emphasized because it can be applicable to almost all waste-treatment processes.

Technology Development and Selection

Historically, waste-disposal and waste-treatment practices have focused initially on methods that can treat or dispose of a large variety of wastes, such as landfills and incinerators. As special procedures became available for specific wastes, combinations of treatment began to be applied to many waste streams.

At this stage, DOE has examined a number of treatment technologies that are very broad in scope. Plasma technology, vitrification, encapsulation, and others were chosen for their expected broad range of applicability to wide ranges of wastes. These technologies will be evaluated carefully but, according to present information, these technologies look promising and mature. Other technologies, such as supercritical water oxidation (SCWO), electrochemical oxidation (EO), and some others, also initially were intended to treat a wide range of wastes, but they are still developmental, and it appears that they may only be used for selected waste streams. As these technologies become more mature, they can be evaluated in a systems approach that defines waste-characterization issues, pre-treatment requirements, treatment, waste streams and waste form, and regulatory/social issues. This systems approach is being applied by DOE in its recent evaluation of thermal-treatment processes and the current study of nonthermal processes.

Thinking of technology as a system designed for treatment of specific types of wastes should be DOE's future approach. Identifying waste composition and treatment systems has begun and appears to be a major effort by DOE that should continue.

Thermal Treatment

DOE has carried out a comprehensive examination of a range of thermal-treatment options in comparison to the existing commercial, slagging rotary kiln incinerator. In view of the risk remaining in developing technologies versus the long-term experience with the incinerators, it is not clear that economic advantages will be gained from applying these new, developing technologies.

However, potential technical and social advantages may be gained from applying technology other than incineration. Plasma-technology investigators claim that the process could treat a wide range of organic and radioactive components with lower gaseous effluents than in the case of incineration. Nevertheless, considerable gas emissions may still occur (possibly with high concentrations of impurities) which would require rigorous control. In principle, the slag residue is a good waste form against ground-water leakage under repository conditions. DOE announced it will be field testing a unit on radioactive waste within two years. Long-term reliability and duty requirements have to be verified before this process can be considered suitable for commercial use in the future (about the year 2000).

Among the group of technologies based on the use of a molten metal bath for waste treatment or the recovery of metals, is Quantum-CEP^{TM}, a trademark of M4 Environmental L.P. The technology is close to commercialization, and a field demonstration using radioactive waste is proposed. The field demonstration experience should also contribute to the evaluation of the application of the technology (e.g., nature of feed materials and end products) and, possibly, needs for further development.

Vitrification treats waste streams contaminated with radionuclides, metals, and organics. It has been field tested and is essentially commercial for liquid high-level wastes. Gas emissions must be controlled during the vitrification process, as in other treatments.

Nonthermal Processes

DOE is carrying out a systems evaluation for the following technologies: catalytic oxidation for organics in water, electrochemical oxidation of organics, electron-beam destruction of organics in water or gas, photo-oxidation of organics in water, high-energy corona discharge for organics in gas streams, and many others. These technologies have been chosen from an initial list of over 200 commonly used technologies. The selected technologies are in the bench phase of development and would appear to be at least eight years from potential commercial operation. It may be possible that these technologies will find an earlier application for specific waste streams that are suited for the attributes of the technology.

A broad range of separation technologies can be applied for pre-or post-treatment of waste. Soil washing and thermal desorption are examples of commercial technologies. In the area of soil washing, increasing the efficiency of removal of pollutants from soil remains a critical issue. Indirectly heated thermal desorption is a commercial technology for removing organic pollutants and mercury from solids. This technology offers organic separation and gas effluent streams that are 2–10 percent of the air emission of incinerators. Indirect thermal desorption should be examined further in any system evaluation for wastes containing organic constituents. Demonstrations with radioactive components are being planned.

Stabilization and Containment

Vitrification can be used to stabilize a range of inorganic and metal wastes. The technology can be applied at different temperatures, using varying process configurations, and using different additives for the glass-making process. The technology is commercial except that more field testing on low-level radioactive wastes will be performed within the next two years.

Polyethylene encapsulation is suitable for many wastes such as debris and residuals and for streams that are not amenable to vitrification. The technology has been field tested and is close to commercialization. Stability of waste and encapsulation metrix may remain a concern in certain cases.

Phosphate-bonded ceramic waste stabilization will be field tested within the next two years on residues from the plasma process.

Summary

DOE is demonstrating a number of technologies that can be applied to the very large range of mixed wastes. This variety of technologies can contribute to the treatment of diverse waste; nevertheless, developing many variants of the same basic technology does not seem to be justified.

At this stage of the development cycle, it seems more important to focus heavily on the waste streams and to examine alternative systems likely to treat the wastes of interest than to demonstrate technology. By combining a range of waste analysis methods, pre-and post-treatment separation and treatment methods, developed technologies, and analyses of the acceptability of the waste product, waste-stream groupings can be identified for which no good solution currently exists and which are therefore candidates for research. DOE has such a program planned for the coming year.

Some problems may require new methods or subprocesses or new approaches. Such problems may, for example, be related to specific volatile metallic components. For these, it is important that priorities be established both for the waste to be treated and for technologies to be developed. More attention should be paid to the evaluation of the related problems and their relative priority.

Much effort is being spent by DOE on developing nonthermal methods for the destruction of organic components in mixed waste. One incentive has been to avoid high temperatures which may generate problems related to off gases and off gas purification. A first impression is that these nonthermal processes are still less developed than thermal processes; nevertheless, they deserve proper attention, for example, for well-specified homogeneous waste.

Potential future use of developmental thermal technologies should be evaluated in terms of risks and technical and economic aspects versus proven technologies. Most importantly, strong public involvement must be maintained to overcome potential hurdles that new technologies will face as their technical problems become more apparent with longer use.

Most treatment facilities have gas emissions. Gas-emission control and real-time monitoring of pollutants of concern are an important area of research that should be continued.

Issues Affecting Technology Development and Use

Impact of Public Involvement/Concern

Prior to 1984, the management of hazardous and mixed waste at DOE facilities was shielded from public review. After agreeing to comply with RCRA and other federal and state environmental laws at its facilities, the DOE initiated a policy of public openness. DOE established advisory committees of stakeholders to interface with facility operators on environmental issues. Similar to the increased public participation resulting from the 1984 Hazardous and Solid Waste Act Amendments and the 1996 Superfund Amendments and Reauthorization Act, the 1992 FFCA further increased public participation in DOE affairs. Also, the states made the facility site plans available to the public.

These actions resulted in the public voicing concerns about conventional incineration and the transport of mixed wastes off-site for disposal. While these concerns are often emotional, it would be inappropriate to label them as only "nontechnical" because they are rooted in the nature of the technology and a risk of vehicular accident during transport, respectively.

DOE has shown responsiveness to these concerns in its mixed-waste technology development strategy and in its mixed-waste treatment plans by focusing on alternatives to conventional incineration and by attempting to plan for the treatment of most wastes at the site where they are currently stored. In addition, DOE has selected continuous monitoring for incinerators as a means of addressing stakeholder concerns regarding toxic emissions as a priority.

Political Issues

Political issues continue to play a role in DOE waste-management technology decisions. Political pressures within states for rapid reform of DOE waste-management programs may have resulted in technology choices in previous state agreements that are in need of review. Furthermore, the large amounts of money required for cleanup and waste management at DOE facilities and the finite DOE budget could create political competition among host states for large projects that may or may not be part of the DOE mixed-waste strategies. Finally, the ultimate political issue becomes the viability of DOE's technology-development plans in the face of major budget cuts proposed by Congress. Constraints on the DOE-EM budget likely will continue for the next several years, placing an emphasis on low cost or highly effective treatment technology and shorter-term returns. DOE should develop a prioritization plan that presents a clear basis for funding technology development during times of severe budget constraints.

Regulatory Reform

The proposed Hazardous Waste Identification Rule (HWIR) planned to be published for public comment in the coming months may have an important impact on the need for treatment capacity for mixed wastes and associated technological development. Because the HWIR is expected to propose concentration thresholds for RCRA listed wastes below which these wastes are no longer considered hazardous, this rulemaking may cause large quantities of mixed waste to be reclassified as strictly radioactive waste and may negate the need for some treatment. The MWFA should closely monitor this rulemaking to understand the impact it may have on DOE's technology development.

Cost/Benefit

The MWFA has determined that 90 percent of the mixed-waste streams can be treated with technologies that currently exist or that can be modified. Therefore, the majority of technology development will likely be focused toward improving these present technologies. Standard measures for evaluating and comparing alternatives should be used, including cost-benefit analysis. Because the MWFA is interested in reducing the overall life-cycle costs, the cost-benefit analysis should entail a broad view of the complete system, including waste-characterization efforts and final waste form for disposal. Decision metrics should be clearly articulated, and flexibility should be built into the decision process to revise the metrics if better metrics are found.

However, decisions pertaining to selection of innovative technologies based solely on cost-benefit analysis should be avoided. In particular, funding basic research with the potential to deliver technologies having large but undefined financial pay-offs in the future shold be supported. The benefits of basic research are often hard to quantify, and holding this research to strict equations of cost and benefit may cause DOE to forego some promising research.

Privatization

Many of the site treatment plans (STP) specify treatment of a large percentage of waste streams in private treatment facilities. The basis for this trend is unclear. The issue of privatization was discussed by the subcommittee with no resolution. Some issues requiring resolution include (1) the degree of latitude to the bidders in specifying and designing technology systems and (2) the proper level within the system at which to privatize (i.e., individual components, treatment units, or entire treatment trains).

Conclusions and Recommendations

Conclusion: Among the criteria for the selection of treatment technologies, the physical and chemical characteristics and volume of the end products—or the need for secondary immobilization—are integral and important issues in waste management. These criteria also mean that the option for a type of disposal environment (not necessarily the disposal site) and current or expected regulatory restrictions related to disposal are of great significance.

Recommendation: DOE-EM should give full consideration to the characteristics of the final waste form from the perspective of its potential disposal environment.

Conclusion: Selection of treatment technology and decisions for development of new technologies should be based primarily on perceived needs associated with specific waste streams. For "near-mature" technologies, the potential advantages and types of wastes treated need further evaluation. Application of available and near-mature technologies may still leave some waste-treatment problems unsolved and, for the latter, new approaches may be required.

Recommendation: DOE should establish R&D priorities on the basis of quantities of wastes, associated risks, available technologies, and regulatory constraints. Ultimately, treatment technologies must be evaluated as a total system, including disposal, and in life-cycle context.

Conclusion: For several categories of wastes, mainly those containing organic components, nonthermal destruction processes may look attractive when compared with established thermal technologies. However, the majority of the nonthermal processes are still in an early stage of development and/or demonstration.

Recommendation: In the comparison of thermal and nonthermal treatment methods and establishment of relative priorities, the stage of development, end-product characteristics, technical and economic advantages, and potential for improvements of thermal processes should be considered.

Conclusion: Adequate characterization, adapted to the requirements of specific treatment technologies and the properties of handled materials, is a critical element for successful and cost-effective implementation of mixed-waste management.

Recommendation: Characterization techniques should be adapted and limited to meet the essential requirements of the treatment processes and waste-management systems.

Conclusion: The permit process and public involvement are critical aspects of any environmental technology-development program.

Recommendation: DOE should increase activities that assist in streamlining the permit process and stakeholder involvement.

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SUBCOMMITTEE ON DECONTAMINATION AND DECOMMISSIONING

Introduction

The end of the Cold War and the downsizing of the nuclear weapons complex present a major change in emphasis and magnitude of the tasks facing the U.S. Department of Energy (DOE). DOE nuclear facilities no longer in use are being deactivated and need to be decontaminated, and DOE believes many must be decommissioned. As stated in *Estimating the Cold War Mortgage: The Baseline Environmental Management Report (BEMR)* (USDOE, 1995a), DOE estimates the scope of the current problem includes approximately 7000 contaminated buildings, of which 700 are candidates for decommissioning. Contained in these structures are, reportedly, over 500,000 metric tons of contaminated metal and mixed units over a billion cubic feet of contaminated concrete. DOE-EM's technology-development program is aimed at developing and implementing technologies that will address these problems safely and cost effectively.

The Decontamination and Decommissioning (D&D) Subcommittee was established to assist the Committee on Environmental Management Technologies (CEMT) in assessing/evaluating technological needs in DOE's D&D Focus Area.

Planning Documents

The DOE provided the subcommittee with three principal draft planning documents to convey the foundation of the focus area's efforts and planned approach to date. These documents were *DOE's Strategic Plan* (USDOE, 1995c), *Management Plan* (USDOE, 1995e), and *Implementation Plan* (USDOE, 1995d). DOE D&D and general resources were also transmitted to the subcommittee at various times *D&D Focus Area Technology Summary* (USDOE, 1995), and *Decommissioning Handbook*

(USDOE, 1994). DOE advised that the three major planning documents are being reviewed within the department and may be issued in final form before the end of 1995. Although the three planning documents will change from time to time to reflect the evolving nature of DOE priorities, the following elements seemed to be lacking:

- a systematic needs assessment;
- a systematic assessment of available technologies including disposal options;
- a matching of available technologies with the needs;
- an identification of technology gaps;
- development of criteria within appropriate constraints (e.g., acceptable risk, regulatory drivers, stakeholder agreements, cost-benefit analyses) to enable priorities to be established; and
- guidelines for development and implementation of a comprehensive, integrated program involving a suite of projects from basic and applied research through large-scale demonstration and implementation depending on the maturity level of the technology.

As a foundation for the selection, evaluation, and prioritization of candidate D&D technologies, a clearly defined set of criteria for D&D technology application and performance is a necessary first step for the D&D Focus Area. Among the more important attributes of the performance criteria are

- technical feasibility,
- compliance with regulatory constraints,
- worker and public health and safety,
- economic viability,
- political/stakeholder acceptability, and
- end-user satisfaction in addressing specific tasks.

The eventual use of DOE sites will determine the end points of the D&D remediation efforts. Establishing quantification criteria for the necessary and sufficient cleanup of DOE sites is certainly a primary factor driving D&D technology development. Whether DOE can develop a system of criteria to yield specific site-cleanup objectives remains to be determined, but DOE should attempt to do so. Remediation of certain sections of DOE sites to pristine levels may well be prohibitively expensive and unnecessary. Many argue that certain sections of DOE sites should be left as "brown fields," suitable for certain kinds of industrial development.

DOE seeks to minimize the financial requirements of its D&D programs by promoting the possible resale of recovered metals, the commercialization of technologies that it might develop, and various privatization efforts. Further comment may be made on these matters as additional information is received and analyzed, but the fact that DOE appears to be relying on a domestic and foreign market potential for yet-to-be developed technologies in the absence of any documented assessment of the status of these D&D technologies and needs raises concern.

Conclusions and Recommendations

Conclusion: DOE EM-50 has stated to the subcommittee that new technologies are needed to perform D&D tasks safer, better, cheaper, and faster than is possible with presently available technologies. However, no documentation of the basis for this premise, which is the justification for the entire technology-development program, has been provided or identified. At the same meeting, the subcommittee heard from EM-40 at headquarters that all necessary technology is in hand.

Recommendation: Using external peer review as appropriate, DOE should establish criteria by which to compare and evaluate the effectiveness of existing and candidate technologies and a means by which deficiencies can be evaluated. The basis for projecting the needs for and or the superiority of future technologies then should be stated explicitly. The process should start with a needs assessment for the D&D Focus Area and should identify available technologies, technology gaps, and criteria for establishing priorities.

Conclusion: The D&D Focus Area Strategic Plan, with its emphasis on relatively mature technologies and large-scale demonstrations, is too narrowly focused.

Recommendation: The D&D Focus Area should revise its strategic plan to provide a basis for a comprehensive D&D technology-development program. This plan should specify a process that will yield a systematic assessment of D&D needs and available technologies, the identification of technology gaps, the development of criteria for establishing priorities, and a justification for demonstration projects that will be funded and executed. The product of this effort should be a balanced program of basic and applied research, exploratory and advanced development, engineering design, demonstration, and implementation.

Conclusion: A strategic plan is best if flexible. Indeed, strategic planners (see e.g., Andrews, 1987; Goold and Quinn 1990; Mintzberg, 1978, 1979, 1981; Mintzberg et al., 1976; Quinn, 1977, 1980) have demonstrated that many of the best strategies emerge without the benefit of a rigid planning document. Although flexibility is very difficult to achieve in the public sector, DOE does not need another formal or rigid plan to follow. It is not evident that any progress on finalizing the draft plans has been made since CEMT's report for 1994 (NRC, 1995), and the goal of producting a "final" plan this year may be unrealistic.

Recommendation: The D&D strategic plan should be a living document. If the planning documents are "finalized" by the end of this year, DOE should include provision for future periodic revisions.

Conclusion: DOE should address planning in terms of a *process* and should not have to contract for the drafting of the strategic planning document. In order for the plans to succeed, DOE decision makers themselves (and not their support contractors) should draft the plans. Many organizations have found that the most valuable aspect of any strategic planning exercise is the *process* of assembling the plan rather than the specific details of the plan.

Recommendation: DOE should set aside time for the planning exercise. The plan will succeed best if it has commitment from the highest and broadest levels of management, so it must include the undivided attention of the highest-level decision makers. If three planning documents are developed, different levels of DOE representatives could draft the different plans, but the strategic planning document must include the highest-level decision makers. The Management Plan should include those responsible for managing the plan. The Implementation Plan should include those individuals who will implement the plan.

Conclusion: The drafts of the Strategic, Management, and Implementation plans are inconsistent in language, definitions, process structure, and criteria and fail to provide a usable roadmap from which detailed scheduling and milestones can be developed within annually approved budgets.

Recommendation: DOE should establish an action plan that leads to the early revision and issuance of each of the three plans. The plans should incorporate specific language, definitions, process structures, and performance criteria that are consistent across the three principal planning documents. Areas of emphasis should include priorities, discussion and integration of performance criteria, assessment of the scope of work vis-a-vis the other focus areas, and related technology development for D&D within DOE.

Conclusion: The D&D Focus Area Management and Implementation plans fail to include adequate recognition of and coordination with appropriate activities underway in other parts of DOE and with independent technology development in the private sector and abroad.

Recommendation: The revisions of the Management and Implementation plans should include an evaluation of private sector and non-U.S. technology developments.

Conclusion: DOE apparently expects benefits will accrue to it by commercialization of newly developed D&D technologies. No indication of source or market potential to support this expectation could be found.

Recommendation: Without a basis for potential commercialization, DOE should not permit consideration of commercial potential to affect the selection, development, or utilization of new technologies.

Conclusion: No basis for establishing levels of site cleanup to be achieved, other than the need to comply with statutory, regulatory, and contractual requirements is evident. End-use risk and cost are also major drivers.

Recommendation: DOE is in urgent need of defining criteria by which the level of site cleanup on a "necessary and sufficient" basis within regulatory constraints can be determined. Such an exercise might indicate current technologies to be entirely adequate to meet cost and schedule targets.

Conclusion: DOE does not have a fully integrated "D&D Technology Needs Evaluation Document" that justifies the large-scale demonstration projects that DOE is scheduled to fund. Four D&D large-scale demonstrations that will showcase specific D&D operations are scheduled for the next two years; however, it is not clear how these demonstrations will be evaluated and documented to capitalize on their successes and failures in future D&D activities.

Recommendation: A cost-benefit study is needed for the three or four most critical D&D technologies expected to reduce the cost of decommissioning significantly without compromising safety. The study should evaluate the status of current technologies nationally and internationally, using external peer review as appropriate, and assess how many dollars can be saved throughout the DOE Complex for each research and development dollar spent to develop new technology or improve existing technology. Current technology-development programs that do not have a return on investment for the development dollars being spent should be terminated. For the scheduled large-scale demonstrations, specific evaluation and analysis procedures should be developed before further funding is committed.

Conclusion: Systemic DOE-wide issues, such as the lack of an "end-use" standard or policy, the ongoing debate between a "national" versus a more region-based management strategy, or the impacts from highly prescriptive regulations or DOE orders, place significant burdens on the successful achievement of technology development by the D&D Focus Area. While such systemic problems are beyond the immediate control of the focus area, the draft documents offer little recognition of these significant concerns and do not propose alternative strategies to compensate for these issues in the development of D&D technologies.

Recommendation: The D&D Focus Area should address these significant larger issues in its planning process, supporting documentation, and structured interaction with DOE, other agencies, its industrial partners, and stakeholders. The draft documents should be re-assessed to highlight areas affected by these systemic problems and to include decision points that address specific issues affecting planned technology development.

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CROSS-CUTTING AREAS AND TECHNOLOGIES OF IMPORTANCE

There are several waste-management or site-remediation technologies central to the DOE waste-management technology-development program that will be used across the five focus areas. Some are formally designated as cross-cutting areas, and their development is being managed under that heading. Others, even though they have generic application, are being managed separately within the five focus areas. Often, the development of technologies in the latter categories is further segmented on a site-specific basis. While site-specific development may be justified on the basis that the wastes and remediation targets vary from one location to another, it often leads to duplication of effort or to gaps in technology development. This problem of uncoordinated R&D activity on topics of generic interest across the focus areas and sites is addressed in the main body of this report.

In some of the five focus-area working papers in Appendix A, the waste-management activities have been classified in the sequence:

- characterization,
- retrieval,
- treatment,
- stabilization, and
- disposal.

This sequence, which seems to apply fairly well to the tank waste, mixed waste, and landfill areas, can be used as a framework to treat the CEMT evaluation and discussion of EM-50 activities.

- Characterization embraces the areas of *site characterization* and *waste characterization*. It also relies heavily on developments in *monitoring and sensor technology*, a technological area that is critical to all five of the waste-management activities and all five focus areas.
- Retrieval is often site and waste specific, but it seems likely that *robotics* will play a critical role in retrieval of certain stored or buried wastes. As noted in the individual working papers, *robotics* is also widely applicable in the characterization, treatment, stabilization, and disposal of toxic and radioactive waste materials.
- Treatment is also a waste-specific activity that can employ a variety of generic technologies. *Separations* is critical to reducing the volume of high-level radioactive waste and to reducing the cost and risk of disposal. For wastes containing high concentrations of organic materials, *incineration* or *supercritical water oxidation* can be very effective in reducing the chemical toxicity and volume of wastes, especially when conducted with up-to-date process technology. The treatment technologies may also embrace homogenization of wastes, especially when the stored materials are as varied and heterogeneous as those in the Hanford, Washington, tanks. *Robotics* have obvious applications in the manipulations involved in homogenizing such dangerous substances. *Monitoring* process streams and emissions will be a critical activity.
- Stabilization of treated wastes prepares them for interim or permanent disposal. It appears that *vitrification* is likely to be the technology for stabilization of high-level radioactive materials at the major tank waste sites. *Vitrification*, grout production, or encapsulation may be options for low-level wastes.
- *Disposal* of solid, stabilized wastes may take place in conventional landfills or in highly secure, radioactive waste repositories. Whatever the disposal mode, *monitoring* of the disposal site may be needed for long periods of time. As noted in the landfill stabilization focus area discussion, this topic of long-term landfill *monitoring* seems to have received less attention than it merits.

The cross-cutting technologies highlighted in italics above are discussed in more detail below.

Site Characterization

Site characterization is critical to understanding subsurface conditions and processes and thus to determining the appropriate course of action for remediation at a particular site. Thorough site characterization, along with technical practicability issues and future land-use scenarios, will enable DOE to select appropriate remedial measures to manage the site. These remedial measures could include one or more of the following:

- source treatment, containment or removal, where practicable;
- ground-water pump and treat for dissolved portions of the plumes;
- in-situ treatment;
- hydraulic containment;
- institutional controls; and
- basinwide ground-water resource management.

To justify the selection of any of these alternatives, the scientific basis of the data used as input to the risk-assessment process or the justification for technical impracticability must be sound. Thus, the extent, quality, and type of site characterization are critical. Too often, too much of the wrong data have been collected at sites across the country (not just DOE sites). The need exists for a comprehensive program that incorporates site characterization as a means to an end, rather than an end in itself. DOE seems to have embraced this philosophy in its cross-cutting efforts for site characterization (e.g., the SEAMIST™[13] and related work that has been performed at the Savannah River Site).

Before selecting appropriate actions at a site, some of the aspects listed below must be understood:

- the nature and distribution in space of the subsurface materials, whether the soils are fine or course grained, heterogeneity of subsurface materials, or whether fractured bedrock exists;
- the hydraulic characteristics of the subsurface and the corresponding behavior of the contaminants in question;
- the mineralogical composition and organic matter content of the rock; and
- the type of contaminants present; whether they are metals, radionuclides, dissolved constituents, separate-phase organic liquids (light nonaqueous phase liquids (LNAPLs) or dense phase liquids (DNAPLs)), and their wettability.

Most of these aspects of site characterization can be fairly straightforward (albeit time consuming and expensive); however, the technology to detect the presence of DNAPL does not exist. Currently, the industry uses "indicators" to assess whether DNAPL is present (e.g., whether DNAPL compounds are present at a

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[13] SEAMIST™ (patented trademark of Eastman Cherrington Environmental) is a concept of drill-hole instrumentation and fluid sample collection using a membrane insertion technique.

percentage of its aqueous or vapor solubility, and whether historic practices indicate that separate phase liquids could have been released).

DOE is actively engaged in efforts to improve DNAPL characterization Because this problem is not unique to DOE and because several other DNAPL characterization efforts are underway both nationally and internationally, DOE should either de-emphasize this effort internally or work collaboratively with other institutions. DOE should strive to reduce its duplication of efforts in this area.

In-field monitoring, imaging, and sensor technology are the best ways to minimize the costs and time associated with detailed site-characterization programs. DOE should concentrate its efforts in this arena, especially if it will attempt to reduce the cost of characterizing plumes and landfills by half in fiscal year 1997, a goal that appears overly optimistic.

DOE is particularly well suited to continue its efforts in the development of monitoring, imaging, and sensor technology given the work at several of the national laboratories. For example, Lawrence Livermore National Laboratory's (LLNL) development and use of electrical resistance topography to track subsurface heat differentials should be expanded into other areas (perhaps the tracking of separate phase liquids). The continued development and refinement of cost-effective field detectors that can assess metals and radionuclides in soils should be encouraged. In addition, DOE's efforts in remote sensing and imaging technologies to elucidate subsurface physical and hydraulic conditions should be encouraged.

In summary, DOE should continue its efforts in the cross-cutting arena of site characterization. To minimize duplication of effort, it should endeavor to form collaborative coalitions both internally and externally. Finally, DOE should review its program periodically to ensure that its technology-development efforts match the needs of the end users in its ever-evolving environmental-management and restoration program.

Waste Characterization

A major element in the strategy for dealing with stored wastes is learning the scope and character of the problem at a given site. Major challenges are (1) characterization of the contents of large storage tanks at sites such as Hanford and Savannah River, and (2) identification of the contents of barrels, especially those buried at many sites across the United States. Some knowledge of the nature of the wastes is needed to design the facilities to prepare the waste materials for permanent disposal. The degree of characterization required will vary from site to site, depending on the extent to which the contents of different tanks and drum-storage areas will be combined and homogenized before treatment and the sensitivity of selected treatment technologies to homogeneity and composition of the feed.

Tank wastes are often inhomogeneous with both liquid and solid phases being found in any vertical cross section of a tank. Even worse, the contents may differ in character across a tank at a given depth. The inhomogeneities in the solid phases are determined conventionally by analyzing core samples taken at accessible points across the tank. This approach is slow, hazardous, and incomplete. Two techniques under development offer considerable improvement in speed and cost effectiveness. The cone penetrometer, which is coming into use, provides considerable physical information on the nature of the phases as well as the positions of the interphase boundaries. Attachment of chemical probes to the penetrometer can give added information about aspects such as pH and moisture content. Similarly, new spectroscopic tools are being developed to characterize the organic materials that are of concern. Another tool under development that should help deal with the lateral inhomogeneity problem is the Light Duty Utility Arm (LDUA), which can move a variety of probes to various positions across the surface of the tank contents.

Another aspect of tank-waste characterization R&D is development of new probes to measure a variety of waste characteristics. A particularly important property is moisture content, because it is believed that 20-30 percent water is needed to prevent explosions from reaction of organic components with the nitrates present in many of the tanks. A thermal neutron technique is in advanced development at Hanford, but an electromagnetic induction technique may permit measurement of moisture content at greater ranges (one foot or more). Several spectroscopic probes such as infrared and Raman spectroscopy are being adapted for use in tanks, both for analysis of the headspace gases and for characterization of species such as nitrate and ferrocyanide in the liquid phases.

The problems of characterizing the wastes stored in drums are as complex at those associated with tank wastes. About 1.5 million barrels of wastes (some radioactive, some hazardous chemicals, and many mixed) are stored at various sites. Apart from the safety aspect, the sheer number of drums makes it impractical to sample intrusively more than a small fraction for conventional chemical or radiological analyses. A major development effort is being applied to nonintrusive techniques, such as acoustic imaging, which can be used to identify the quantity, density, and phases of drum contents. This information, coupled with targeted sampling, can provide the basis for choice and design of treatment techniques to be applied at a site. If nonintrusive characterization can be extended to some assessment of the composition of drum contents, it will be a major contribution to the strategy for drum-storage remediation. For drums containing radioactive material, external multispectral emission radiation spectroscopy can also help identify the whole waste content or anomalous drums.

The development of technology for imaging and analytical characterization of wastes stored in tanks and drums seems to receive appropriately high priority in the EM-50 program. The technology development appears to be well focused toward possible applications in the remediation programs. It is not clear how well EM-50's work in this area is integrated with that of the potential implementers and whether new characterization techniques are being implemented as rapidly as possible.

Monitoring and Sensor Technology

The technologies for monitoring emissions, controlling processes, and performing in-situ analyses present large opportunities for savings of time and money in waste management and environmental restoration, not just for DOE, but also for other federal agencies and for private industry. Development of advanced sensors and monitoring techniques is important to all five focus areas and plays a critical role in the characterization of tank wastes, as noted in the "Waste Characterization" section above.

Monitors that analyze gas composition are needed to characterize the headspace in tanks; the air in work places and drum-storage areas; and emissions from incinerators, plasma hearths, and other waste-treatment facilities. Gas chromatography has been a standard tool for these analyses but is being enhanced continuously in both versatility and specificity by development of new types of detectors such as ion-trap mass spectrometry. Direct sampling mass spectrometry and long-path Fourier Transform Infrared (FTIR) spectroscopy are in advanced development and the early stages of implementation for vapor and gas analyses. DOE National Laboratories are actively developing newer, more sophisticated technologies such as surface-acoustic-wave sensors and thin-film detectors.

Monitoring gases in the soil over buried wastes, in atmospheric plumes, and in work areas can utilize both new sensors and new ways of deploying them. Vapor-analysis sensors attached to cone penetrometer probes can provide information on volatile contaminants in soil. Similar devices can provide valuable data on the atmospheres where buried wastes are being excavated and on the need for robotics.

Monitoring of soil and ground-water contamination can be expedited by new techniques such as electrical resistance tomography and radar holography in addition to standard techniques such as gas chromatography and metal analyses (see "Site Characterization" section above). The goal for new technology development and implementation in this area is to reduce the cost of characterizing plumes and landfills by half in fiscal year 1997. A variety of new alpha-and beta-particle detectors is being developed to assess and map radioactive soil contamination.

Looking to the future, decommissioning and decontamination of storage and waste-treatment facilities will require a variety of techniques to characterize the contamination of surfaces and solids. New tools, such as secondary ion-mass spectroscopy and laser-induced fluorescence techniques may facilitate this work.

The Characterization, Monitoring and Sensors cross-cutting area has outstanding opportunities to contribute to the overall EM program, but two complex, interrelated issues will require continuing management attention:

- *Matching technology development to the needs of the technology implementers.* This task is exceptionally difficult because, on the supply side, there are a multitude of technology developers ranging from large defense contractors, universities, and national laboratories, to small entrepreneurial firms offering unique technologies. An "opportunity and challenge" is to make the best use of the outstanding technological expertise in the programs supported by DOE's Office of Energy Research. On the demand side, there are hundreds of needs at a multitude of sites with only loose coordination among the responsible managements. A hitherto unattained level of cooperation and coordination will be needed to fit all the pieces together optimally.
- *Matching technology development to the evolving needs of the waste management and environmental restoration programs.* The largest current need is probably for technology for site and waste characterization. When the waste-treatment and waste-disposal operations grow larger, there will be major needs for process and workplace monitoring instrumentation. When site-remediation programs are completed, different monitors will be required during the decommissioning and decontamination operations. Long-term monitors will be required to assess the integrity of landfills and waste-storage facilities. Because the design, development, demonstration, and deployment of new monitoring technologies requires periods of years, it is important that the technology-development strategy be phased to anticipate the evolution of the environmental-remediation activities.

Robotics

DOE Needs

Robots with various levels of complexity and sophistication may be necessary to solve many of the DOE-EM problems. The equipment and systems selected are application dependent and will probably depend on funding available at the time of the work. In many instances, due to the hostile environments, simple commercially available teleoperated devices may be justified due to safety reasons for specialized work that is not labor intensive. For large volumes of repeatable work in structured and unstructured environments, such as for D&D tasks, development of specialized automation (robotic and telerobotic devices) may be justified. These developments do not require fundamental research nor new technologies but basically require the adaptation of existing proven systems to specific problems. For some cases (tank-waste retrieval, for example), robotic specialty systems will be required. Demonstration, testing, and evaluation of systems are essential. Although robotics is not a new technology, each new and unique application requires specific engineering and some development work.

Technology Status

Commercial robotic systems are available and currently are being applied to DOE's environmental-restoration and waste-management programs. Typically, robots are computers with mechanical peripheral devices, and robotic-supporting technologies include computer vision, computer graphics, computer architecture, and sensory systems. Much advancement has been made in this area during the past decade. The availability of small, capable, and affordable computers has promoted widespread use of this technology. Computer graphics for robotic control systems provide effective and sophisticated interfaces between humans and robots. A variety of robots is commercially available. Industrial robots (robot arms) are available in a variety of configurations from companies in the United States, Europe, and Japan. Special systems are available for nuclear environments. Mobile robot systems are currently working "around the clock" in security applications for the military, industrial warehouses, and art museums (Everett et al., 1995). Unmanned vehicles have been developed for the DOD (Gage, 1995). Various forms of "pipe crawlers" are commercially available. These systems are generally teleoperated sensor packages used for inspection of interior surfaces, such as pipes and ducts, inaccessible by humans. Teleoperated mobile systems with tracks or wheels are available from several companies. These systems have been applied in a variety of applications, including police operations and nuclear process operations (American Nuclear Society, 1984, 1987, 1989, 1991, 1993, 1995).

DOE Robotics Development Program

The DOE-EM Office of Science and Technology (OST), in cooperation with Morgantown Energy Technology Center (METC), has ongoing projects with industry and academia to develop solutions for DOE-EM problems (USDOE, 1995a,b, in press). The Robotics Technology Development Program (RTDP) is a major technology cross-cutting effort in EM (USDOE, 1993), which is performing applied research and development for all five of DOE's focus areas. The following section focuses on the D&D efforts.

Major emphasis in the RTDP program for D&D is on practical systems and capabilities that can be used in facility de-activation and ongoing surveillance and maintenance activities that will reduce costs, enhance safety, and improve the quality of operations. Four National Laboratories (Oak Ridge National Laboratories, Sandia National Laboratories, Idaho National Engineering Laboratories, and Pacific Northwest Laboratories) and the Savannah River Technology Center are the DOE participants. Six industries and five universities also participate in this program. Major opportunities for robotics have been identified for mapping, characterization, inspection, dismantlement, and decontamination. Current major activities for the program include: a Selective Equipment Removal System (SERS) which is a mobile vehicle system under development for equipment removal in decommissioning operations; the Facility Mapping System (FMS) which is a computer system for the management of characterization data from a facility; and the Mobile Automated Floor Characterization System (MACS) which is an autonomous, mobile floor characterization system for efficient and effective characterization of large floor surfaces, such as the gaseous diffusion plants. The Small Pipe Characterization System (SPCS) and Internal Duct Characterization System (IDCS) will be used to examine remotely interior surfaces for visual inspection and characterization. A Pipe Asbestos Insulation Removal Robot is under development for 4'-8' diameter pipes. A remotely operated vehicle with CO_2 blasting for decontamination of surfaces is under development. This unit will remove paint from surfaces, such as floors in K-25 facilities.

Other cross-cutting efforts are underway. Robotic technologies are being developed and demonstrated (e.g., the Light Duty Utility Arm) for characterization and removal of underground tank waste at Hanford. Laboratory automation development is underway for the analysis of materials from underground storage tanks at Hanford and samples from other process operations. Autonomous robotic systems are under development for the visual inspection of drums of low-level waste stored in warehouses at Fernald, Oak Ridge, Idaho, Rocky Flats, and Hanford.

Related Robotics Development Activities

DOD and NASA have in-house R&D programs in robotics. Research programs, existing at major universities, are addressing robotics technology issues such as unique mechanical configurations, path planning and control, mobile navigation, sensory systems and sensor fusion, computer architecture, real-time systems, computer inspection, hardware and software reliability, and computer graphics. Many of these programs are supported by grants and contracts from DOD, DOE, and NASA. Therefore, benefits from this work are available for DOE applications.

Concerns

Although robotic technology demonstrations and analyses have been budgeted and scheduled for key components of the DOE RTDP, evaluation criteria for the projects and criteria used for budgeting and prioritization of robotics technology projects are not evident. Fiscal Year 1995 funding within EM-50's RTDP supported a demonstration during September 1995 at the ORNL K-25 plant for MACS. That demonstration was not conducted, and, currently, MACS is not an "active" project. This system has been estimated to have high potential for cost savings in facility D&D projects. In Fiscal Year 1995, EM-50's RTDP program had a task entitled The Surveillance and Maintenance Risk and Cost Reduction Evaluation Methodologies (related to robotic systems). The methodology was scheduled to be applied to an existing DOE facility in September 1995, but apparently, that work has not been completed at a specific site.

Although the RTDP appears to have good projects and intentions, it is not clear to CEMT that priorities are ordered correctly to support the overall EM program or if efforts are being made to take advantage of works at other federal agencies.

Separations

Separations, particularly of short-lived radionuclides from long-lived species, play significant roles in dealing with the waste streams considered in the five focus areas, and are especially important in dealing with wastes containing high-level radioactivity. As outlined in the report *Nuclear Wastes: Technologies for Separations and Transmutations* (NRC, 1996), separations would be absolutely critical to the transmutation approach to dealing with either military or nuclear fuel waste materials.

More immediately, however, both the costs and risks of disposing of tank wastes at Savannah River, Hanford and the Idaho National Engineering Laboratory (INEL) (as well as calcined wastes at INEL) are directly related to the efficiency of separations in the wastes to be vitrified (see section on "Vitrification" below) and the number of separation steps required. The latter point can be illustrated by considering options for disposal of tank wastes. One option would be to vitrify the entire contents of the tanks, without any separations, and to dispose of all the waste material in a high-level repository. This option likely would be excessively expensive because of the cost of disposal in a facility such as Yucca Mountain. The cost could be reduced substantially by separation of the radioactive components from the great mass of nonradioactive salts. On the other hand, the cost of disposal could be minimized by complete separation of low-level waste from the high-level material that requires expensive disposal. While this option would be attractive from the viewpoint of disposal costs, it is not feasible because the technology for complete separation does not exist currently.

The optimal balance of processing cost and risk versus disposal cost and risk generally involves a modest number of separations steps. Determining this balance is a major challenge in the proposal that the separations and vitrification processing of the Hanford tank wastes be privatized. If the contractor were to do an inadequate separation of high-and low-level wastes, the cost of high-level storage to be borne by DOE would be excessive.

Beyond the challenge of minimizing costs, the design of separations processes for disposal of tank wastes must also minimize risks to plant personnel and the public. Increases in the number of process steps lead to increased potential for radioactive emissions. Each time a waste stream is moved or processed, the possibility for release of gases, liquids, or solids exists. Each step also generates secondary wastes arising from the reagents used to carry out the desired separations. As with cost, the minimization of risk requires an optimal choice of the number of separations to be performed.

Minimization of cost and risk requires a systems approach to the design of the overall disposal process. The conceptual design of the complete waste treatment system should identify both the number and kinds of separations required. It is likely that many of the newly identified separations processes (such as those for ^{137}Cs and ^{90}Sr discussed below) are not developed sufficiently for immediate application. Prompt identification of the separations needs will facilitate the work of organizations such as EM-50 who are responsible for development of the necessary technology. The development path from identification of a promising chemical separations process through bench-scale and pilot-scale demonstration to actual implementation requires years of effort. However, the resources and time spent on technology development can yield substantial benefits in terms of reduced costs and risks in the ultimate application. These benefits accure to all stakeholders in the waste-management process from the residents of nearby communities to the U.S. taxpayer (currently, nuclear utility-rate payers), who must, ultimately, bear the cost for disposing of DOE's wastes.

The Efficient Separations and Processing (ESP) cross-cutting area has supported the development of several promising, innovative techniques for separation of cesium and strontium. Approaches for cesium include

- sequestration into high-capacity, layered silicotitanates;
- extraction into ion-specific organic ligands that are encapsulated in permeable polymer membranes; and

- complexation to cobalt dicarbollide ions that are selective for binding Cs and Sr. These complexants may be used either in liquid-liquid extractions or as components of ion exchange resins.

This part of the ESP program has made good use of the expertise of private industry to synthesize developmental quantities of inorganic materials, for proprietary membrane technology, and for ligand design and synthesis. Examples include synthesis of crystalline silicotitanates (CSTs), sodium titanates, and membrane-supported organic extractants that are effective ion-exchange materials for Cs and Sr. These materials, developed under ESP contract, have been brought to pilot scale or commercial production and have been tested on tank wastes or simulants from Savannah River, Oak Ridge, INEL, and Hanford with encouraging results. The CSTs, now commercially available from University of Pennsylvania Molecular Sieves as IONSIV IE-910 and 911, have proven very effective with decontamination factors of one million for Cs and 10,000 for Sr (Brown et al., 1996). Sodium nonatitanate, manufactured as powders or pellets by Allied Signal, Inc. has proven similarly effective for strontium and also appears promising for Am, U, and Pu (Yates et al., 1993). The sodium nonatitanate also has been incorporated in the novel membranes developed by 3M Company, which show mechanical advantages over ion exchange columns in some waste-treatment applications. The 3M Empore™ membranes also have been used with organic ligands tailored for ion specificity by IBC Advanced Technologies (Kafka, 1996). This technology represents another promising example of an ESP initiative that uses the synthesis and manufacturing capability of private industry very effectively. Some of the techniques developed for cesium also appear promising for strontium, although the systems need more development of the strontium separation processes.

To develop an integrated system for separation of the materials contained in complex mixtures such as those in the Hanford tanks, it is desirable that R&D be carried out simultaneously on the various nuclides of interest. For example, one must develop compatible technologies for dealing with technetium and the transuranic elements in addition to cesium and strontium. Technetium is a concern both as a long-lived component of tank wastes and, in other circumstances, as a potential ground-water contaminant. In tank remediation, technetium is a potential source of problems in vitrification. As such, it may possibly require a separate stabilization process to prepare it for long-term storage.

The development of selective techniques for the separation of technetium (mainly TcO_4^-) from waste streams containing high concentrations of other materials appears to be less advanced than for Cs and Sr, but similar extraction and ionexchange techniques may be applicable if extractants and resins can be developed. For the transuranic elements, further refinement of the TRUEX process may lead to adequate specificity. All these metal-selective processes need to be integrated with each other and with those for priority nonradioactive waste materials.

The ESP program seems to be managed quite effectively. There has been considerable emphasis on understanding specific needs for separations in the remediation of tank wastes and other mixed waste streams. The message that "Success is implementation!" seems to be understood by most of the contractors supported by this program, although the response to the message is probably mixed. Most of the contractors presenting their work at the 1995 ESP Technical Information Exchange appear to have defined useful practical objectives for their R&D programs. Although the ESP program is well run and reasonably successful, two concerns remain.

First, the effectiveness of the interactions between the ESP participants and those supported by the Office of Basic Energy Sciences (BES) and Office of Health and Environmental Research (HER) programs within the Office of Energy Research (OER) can be improved. Considerable progress has been made in strengthening ties to basic research in areas such as design of metal-selective ligands, but major gaps remain in the coordination of the OER programs with those of potential clients in EM-50. Fundamental research relevant to the needs of DOE-EM is done in BES-and HER-supported programs, but coordination of the research directions in these programs with the needs of EM generally is lacking. EM-50 seems well positioned to serve as an interface between the basic-research programs of OER and the technology implementers in EM.

Second, it remains to be demonstrated that innovative developments in separations technology from the ESP program can be moved into the implementation programs of the five major focus areas in a timely and cost-effective manner. As an example, there are obvious problems in replacing the cumbersome tetraphenylborate-based precipitation of cesium in the Savannah River vitrification technology with one of newer cesium separation technologies mentioned above. The time required to replace the tetraphenylborate precipitant with a new inorganic reagent or with an ion-exchange material such as the CSTs described above depends not only on technological requirements, but also on slow, bureaucratic evaluation processes in DOE and in relevant regulatory agencies.

Incineration

The term "incineration" covers a variety of treatment processes that have the common objectives of volume reduction and destruction of organic (usually nonradioactive) components of wastes, but differ in such essential features as temperature, heating system, residence time, furnace design, post-combustion and off gas purification systems. In the lower temperature ranges (~1000°C), the end product is in the form of loose ash, which may require a secondary treatment for consolidation. At higher temperatures (>1300°C), the end product may be a slag, which may not require any additional form of consolidation or insolubilization.

Common to all forms of incineration, although to very different degrees, is the formation of volatile or semi-volatile components that are vented with the off gases. These volatiles may contain hazardous radioelements (e.g., Cs and Ru) or complex organic components, such as dioxins. However, it should be stressed that emission of the latter can be prevented through optimization of the combustion conditions and the use of an adequate gas-purification system. Volatilities of radionuclides and metals (e.g., Hg) also can be extracted by the gas-purification system.

Because of the potential advantages of incineration (flexibility with regard to feed material, broad range of applications, experience), it would be a mistake to apply to all forms of incineration a generalized "poor-quality" label to be avoided and/or substituted by other, still to be proven, processes. Modern incinerators, adequately designed and operated, can comply completely with the most stringent environmental regulations.

The Subcommittee on Mixed Wastes will contribute to the evaluation of types and operational conditions of incinerators that meet relevant environmental criteria and identify areas for further development, if needed.

Supercritical Water Oxidation (SCWO)

A system based on the use of supercritical fluids (e.g., water at pressure and temperature above the critical point) has been proposed for the destruction of the organic fraction of some mixed wastes (oils, detergents, solvents, complexing chemicals, mixtures of organic residues) (see also USDOE, 1994).

The SCWO process is still being developed, but it offers some potential advantages over high-temperature processes, such as

- easy to handle off gases,
- little or no volatilization of radioactive contaminants, and
- fewer problems of public acceptance.

However, the limitations of SCWO processing include

- corrosion at high temperature and pressure,
- handling of solid residues and precipitates in the supercritical fluid reactor,

- lack of practical experience and knowledge of basic reaction phenomena, and
- concerns about handling toxic substances at high temperature and pressures.

It also should be noted that, if the waste contains significant quantities of radioactive components, the residue requires an adapted form of treatment or immobilization.

Some preliminary impressions of the SCWO process so far are that

- SCWO has to be followed by another immobilization process,
- it is not yet clear for which variety of waste streams the process will be applicable,
- the system appears to be most promising for destruction of organic components in aqueous effluents,
- practical difficulties (corrosion, handling) have to be solved, and
- the practical applicability remains to be demonstrated.

Therefore, although the SCWO processing offers attractive potential, it is doubtful whether it will assume an important role in the handling of radioactive wastes in the short term.

Vitrification

Containment of radioactive materials in glass has been selected by DOE as a versatile, widely applicable approach to the safe and efficient management of high-level radioactive wastes. Major vitrification facilities are in place at the Savannah River and the West Valley sites. Planning is well advanced for a facility at Hanford. Installations are in the early construction stages at the Oak Ridge and Fernald sites.

The potential applications of vitrification to radioactive wastes are very broad, including HLW and LLW from the Hanford waste tanks, in-situ vitrification of wastes in the soil at several sites, and thorium and radium residues at the Fernald Site from extraction of uranium from very rich Belgian Congo ores during the Manhattan Project.

Borosilicate glass has been selected by DOE for production in its vitrification plants. Other potentially useful glasses that might have been chosen include phosphate glass, lead-oxide based glasses, and aluminosilicate-based glasses. Borosilicate glass was chosen because of the broad base of knowledge of its properties as a function of composition, the very large experience base that exists with its use in radioactive waste containment (particularly in France, Germany, and the United

Kingdom), its broad applicability to a variety of wastes, and because of the large investment made in it. This investment is both in dollars and in establishing its acceptance and credibility with policy makers and with the public.

Several significant problems exist with the use of borosilicate or any other type of glass for waste containment. The most important problem is that no performance criteria for the waste form have been promulgated by USNRC. Therefore, no target guidelines for waste-form producers exist. Another severe problem is that a very wide range of waste compositions must be accommodated by any waste-vitrification process. Otherwise, there must be very substantial feed pretreatment to produce a uniform feed to the vitrifier. This problem is most severe with the wastes from the Hanford tanks. If vitrified wastes of a spectrum of compositions are produced, it is necessary to qualify them all for disposal, which is very expensive and time consuming.

Finally, there are several processes that are not vitrification in the usual sense but have the potential to produce vitrified wastes. Examples of these are the Glass Material Oxidation and Dissolution System (GMODS) process being developed at ORNL and the Quantum-CEP™ process developed by the M4 Company.

Disposal

Disposal is an integral—albeit the final—part of any waste-management scheme. The selection of a disposal environment as well as the related engineering structures must be based on objective criteria with regard to type, quantities, volumes and characteristics of wastes. Consequently, these criteria will also be important in the selection of treatment/immobilization processes and the many sub-processes they comprise. The treated material eventually becomes the "source term" in any evaluation of the environmental impact of a waste-management program, which includes societal issues such as inadvertent human intrusion into the waste disposal facility. The types of human intrusion scenarios that are assumed are a matter of policy.

Disposal environment and source term are two closely interacting factors, because they control the solubility and mobility of radioelements and, hence, their eventual impact on population. This is also the case for nonradioactive but hazardous components of wastes. Therefore, recognizing that final evaluations depend on the selection of a site or geologic formation, waste-treatment or conditioning must be considered as part of any waste-disposal program.

Removing hazardous waste materials from an undesirable location (e.g., contaminant plume, disused production or laboratory facilities, unacceptable disposal sites) is often essential. When waste retrieval is required, one must have a clear view of the final destination of the resulting waste materials. Relocation of materials may be a poor practice if it does not solve the ultimate disposal problem.

The foregoing also illustrates the crucial importance of characterizing the treated end products to allow prediction of their behavior in the disposal environment. The inventory of hazardous material is only the first step of characterization. Understanding and quantification of interactions between treated/conditioned wastes and their future disposal environment are at least equally important.

Meeting quantifiable regulatory requirements can be a good guide in evaluating compliance with safety criteria. However, more must be done to ensure that the system as a whole meets basic health and safety risk requirements. Evaluation of the latter is the main objective of case-specific quantitative health and safety risk assessments.

The volume of material for disposal is an important factor in the total cost of a disposal program. In particular, it can be used as a preliminary guideline to select processes for treatment or preconditioning of wastes with the intention of minimizing the volume of waste requiring expensive disposal site preparation and maintenance. Nevertheless, two caveats are important:

- Because of the magnitude of general expenses (for R&D, site selection, administrative and legal procedure, which may be independent of volume and quantity, construction of basic infrastructure, and surveillance), there is not necessarily a linear relation between volume and disposal cost. The issue must be analyzed carefully to determine the relative advantages of putting large efforts in volume reduction prior to treatment and disposal.
- In the case of heat-producing waste, the size of the disposal infrastructure may be determined less by the total volume of waste than by the heat-dissipation capacity of the disposal geologic formation.

Choice of Disposal Sites

The acceptability of a given waste type and waste form in a given disposal site depends on two different evaluation measures:

- the confining power of the natural and engineered barriers, including the waste form, which will prevent the radionuclides or toxic chemicals from being released into the environment for several scenarios, and that will meet the regulatory criteria applicable to the specific disposal site. This confining power may limit both the activity of each waste package and the total capacity of a given site.

- the duration and type of constraints that will be applied to the future land use when disposal is completed. This factor will generally limit the amount of long-lived radionuclides (mostly alpha emitters) that can be accepted in a given waste form, based on various scenarios of future land use (e.g., residential area, road construction site, etc.).

At this stage, it is not clear which of the basic options DOE is considering for the disposal of each type of waste, the constraints that each of these options will put on the maximum loading of the waste (e.g., on alpha emitters), and the confining power of the acceptable waste form.

DOE should establish a list of the disposal options considered for waste disposal, both nationally and at each local site, and the constraints that these options impose on the waste composition. The waste form should then be specified, based on generic and site-specific risk assessments. Existing disposal technologies should be used to make these risk assessments.

For each disposal option, an estimate of the cost of disposal should be made as a function of the total size of each disposal site, because cost is not linearly dependent on the amount of waste.

The adequacy of DOE's options for the safe disposal of wastes generated by each remediation activity needs to be addressed. This adequacy should be evaluated both with the existing (or planned) waste-production technology and characterization and with each new technology that is proposed or developed.

Based on the comparison of the chosen disposal options and waste-acceptance criteria, it is recommended that DOE should produce a plan showing the final destination of each waste type. Such a plan may reveal

- the lack of disposal options for a given waste form;
- the need to optimize disposal site locations to minimize transportation and costs;
- the economic incentive to improve a waste form, a waste-separation technique, or a volume-reduction effort, based on the cost of disposal; and
- the need for improved disposal technology.

Landfills

Many of DOE's cleanup efforts deal with existing landfills that may cause threats to people or the environment. Waste is characterized, and the risk associated with the presence of the waste in the landfill is assessed. If the risk is considered unacceptable, three options are available as discussed in the Landfills Subcommittee report:

- excavation and redisposal elsewhere, possibly after ex-situ treatment of the waste and contaminated soil;
- in-situ treatment (e.g., vitrification, grouting); and
- site confinement by additional engineered barriers such as caps, walls, and floors.

Choosing between these options should be based on criteria for the long-term land use, risk assessment analysis for each option, including risk to workers, and costs.

To put the advantages of each option into perspective, it is essential that the same information be available for the redisposal of the waste (after treatment) in another disposal site, if the excavation option is considered. Therefore, for each landfill reclamation project, DOE should consider potential disposal sites where these risks and costs are known. Until this information is available, the decision for treating a landfill site cannot be complete.

New Technologies for Waste Disposal

The R&D in the area of landfills addresses issues such as confinement or site characterization (geology, hydrology) that are also relevant for the development of new disposal sites. However, DOE should also devote attention to the following areas:

1. Incentives, benefits, and costs of disposal of certain LLW in underground-mined repositories, as is done in Sweden, and planned in the United Kingdom and Germany.
2. Incentives, benefits, and costs of a disposal option where the objective is *not* confinement, but enhanced in-situ treatment of the waste in a "disposal" unit, to remove as much radioactivity or toxicity as possible. New technologies that are studied for in-situ landfill remediations (bioremediation, oxidation, acid leaching, etc.) in specially designed engineered structures (e.g., trenches where the waste can be leached and the liquids collected from below). The concept is that all elements removed from the waste (such as gas or liquids) must be recovered by an engineered system. Instead of being immobilized, the waste form should be easily leachable. All collected effluents should be treated (immobilized in a good matrix form for, for example, deep disposal). This form of "disposal" could be seen as a volume-reduction operation, because the radioactive materials would be recovered and disposed of elsewhere. The disposal treatment site would eventually be turned into a confining

site (e.g., by capping) when the residual level of activity is considered acceptable for the designated land use of the site[14].

Finally, it is recommended that DOE devote considerable attention to defining the needs for air, water, and soil monitoring adjacent to landfills and repositories. Once these needs are defined, it will probably be necessary to focus on development of inexpensive but reliable monitoring techniques for long-term surveillance of disposal sites.

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[14] This concept has been put in operation for a toxic industrial waste site in Montcanin, France, which was closed in 1989 because of unacceptable contamination of the environment (air and water). The site is presently in the construction phase of the drainage system, the capping and leachiong system were installed in 1993. (A description can be found in the work of Marsily, G. de, 1992).

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Appendix B

Statements of Task

COMMITTEE ON ENVIRONMENTAL MANAGEMENT TECHNOLOGIES (CEMT)

Statement of Task

The objective of the Committee is to provide independent review and recommendations to the Department of Energy, Assistant Secretary for Environmental Management (DOE-EM), on environmental management technology developments impacting DOE weapons complex facilities.

The Committee would:

1. Review and evaluate DOE-EM's technology-development programs including guidelines, methodologies, protocols, tests, demonstrations, and applications in the context of the relative importance of problems facing DOE-EM;
2. Identify, review, and recommend as appropriate new technical criteria and emerging technologies in environmental management relevant to DOE-EM;
3. Review technology transfer and commercialization for technology programs in DOE-EM; and
4. Issue reports, recommendations, and options on DOE-EM's technology development.

A key function of the Committee would be to ensure that a set of activities from basic research through commercialization is encouraged and promoted. The Committee would also address issues and resolutions of problems related to the development and use of technologies for environmental management.

The Committee would operate on a continuing basis. It would consist of about 15 members of international reputation with strong backgrounds in disciplines relevant to environmental management technologies. The Committee would meet quarterly or more frequently if required.

During March of every year, the Committee would submit a peer-reviewed report to the Assistant Secretary for DOE-EM, listing specific conclusions and recommendations of the studies which the Committee has undertaken during the year. The Committee would also prepare topical reports, if timeliness requires it.

DOE-EM will receive 20 copies of each report, additional copies will be provided to the NRC Committee members and other parties in accordance with NRC policy. These reports would be made available to the public without restriction.

SUBCOMMITTEE ON CONTAMINANT PLUMES

Statement of Task

The Subcommittee on Contaminant Plumes is established with a view to assist the Committee on Environmental Management Technologies (CEMT) as one of the five major focus areas.

The subcommittee will review the DOE documentation including (1) DOE's Remedial Action Program Information Center (RAPIC) bibliography, (2) EPA's Cleanup Information (CLU-IN), (3) Vendor Information System for Innovative Treatment Technologies (VISITT), and (4) Alternative Treatment Technology Information Center (ATTIC) Bulletin Board. The subcommittee also will review the pertinent technical literature, and consult with experts in the field to ensure that state-of-the-art documentation is available on the different technical issues and developments involved in contaminant plumes remediation. If not already available, the subcommittee shall prepare a report including the advantages and disadvantages of each method including cost and risk reduction as well as sensitivity to cleanup levels and time constraints.

The subcommittee will identify the greatest needs in the focus area and the reasons for identifying the technologies being developed. It should identify the difficulties in bringing the technologies being developed to fruition. The subcommittee will further address potential for industrial applications and pay-offs of the technologies being developed to DOE and industry, including foreign markets. The subcommittee should also identify new technologies which have scope for development. It should recommend actions as to what else should be done and how to accelerate the process. This information should be presented as a report to the parent committee.

The subcommittee as a whole, or its members separately, will visit representative DOE Weapons Complex facilities to get first hand information and interact with scientists working at the sites.

Topical reports as indicated above, as appropriate, and minutes of the subcommittee meetings, will be submitted as inputs to the work of CEMT. The subcommittee chairman will provide an annual report to CEMT on December 1st every year.

SUBCOMMITTEE ON DECONTAMINATION AND DECOMMISSIONING

Statement of Task

The Subcommittee on Decommissioning and Decontamination is established with a view to assist the Committee on Environmental Management Technologies (CEMT) as one of the five major focus areas.

The subcommittee will review the DOE documentation including (1) DOE's Remedial Action Program Information Center (RAPIC) bibliography, (2) EPA's Cleanup Information (CLU-IN), (3) Vendor Information System for Innovative Treatment Technologies (VISITT), and (4) Alternative Treatment Technology Information Center (ATTIC) Bulletin Board. The subcommittee also will review the pertinent technical literature, and consult with experts in the field to ensure that state-of-the-art documentation is available on the different technical issues and developments involved in decontamination and decommissioning of weapons complex facilities. If not already available, the subcommittee shall prepare a report including the advantages and disadvantages of each method including cost and risk reduction as well as sensitivity to cleanup levels and time constraints.

The subcommittee will identify the greatest needs in the focus area and the reasons for identifying the technologies being developed. It should identify the difficulties in bringing the technologies being developed to fruition. The subcommittee will further address potential for industrial applications and pay-offs of the technologies being developed to DOE and industry, including foreign markets. The subcommittee should also identify new technologies which have scope for development. It should recommend actions as to what else should be done and how to accelerate the process. This information should be presented as a report to the parent committee.

The subcommittee as a whole, or its members separately, will visit representative DOE Weapons Complex facilities to get first hand information and interact with scientists working at the sites.

Topical reports as indicated above, as appropriate, and minutes of the subcommittee meetings, will be submitted as inputs to the work of CEMT. The subcommittee chairman will provide an annual report to CEMT on December 1st every year.

SUBCOMMITTEE ON HIGH-LEVEL WASTE IN TANKS

Statement of Task

The Subcommittee on High-Level Waste Tanks is established with a view to assist the Committee on Environmental Management Technologies (CEMT) as one of the five major focus areas.

The subcommittee will review the DOE documentation including (1) DOE's Remedial Action Program Information Center (RAPIC) bibliography, (2) EPA's Cleanup Information (CLU-IN), (3) Vendor Information System for Innovative Treatment Technologies (VISITT), and (4) Alternative Treatment Technology Information Center (ATTIC) Bulletin Board. The subcommittee also will review the pertinent technical literature, and consult with experts in the field to ensure that state-of-the-art documentation is available on the different technical issues and developments involved in high-level waste tanks remediation. If not already available, the subcommittee shall prepare a report including the advantages and disadvantages of each method including cost and risk reduction as well as sensitivity to cleanup levels and time constraints.

The subcommittee will identify the greatest needs in the focus area and the reasons for identifying the technologies being developed. It should identify the difficulties in bringing the technologies being developed to fruition. The subcommittee will further address potential for industrial applications and pay-offs of the technologies being developed to DOE and industry, including foreign markets. The subcommittee should also identify new technologies which have scope for development. It should recommend actions as to what else should be done and how to accelerate the process. This information should be presented as a report to the parent committee.

The subcommittee as a whole, or its members separately, will visit representative DOE Weapons Complex facilities to get first hand information and interact with scientists working at the sites.

Topical reports as indicated above, as appropriate and minutes of the subcommittee meetings, will be submitted as inputs to the work of CEMT. The subcommittee chairman will provide an annual report to CEMT on December 1st every year.

SUBCOMMITTEE ON LANDFILLS

Statement of Task

The Subcommittee on Landfills is established with a view to assist the Committee on Environmental Management Technologies (CEMT) as one of the five major focus areas.

The subcommittee will review the DOE documentation including (1) DOE's Remedial Action Program Information Center (RAPIC) bibliography, (2) EPA's Cleanup Information (CLU-IN), (3) Vendor Information System for Innovative Treatment Technologies (VISITT), and (4) Alternative Treatment Technology Information Center (ATTIC) Bulletin Board. The subcommittee also will review the pertinent technical literature and consult with experts in the field to ensure that state-of-the-art documentation is available on the different technical issues and developments involved in landfill stabilization. If not already available, the subcommittee shall prepare a report including the advantages and disadvantages of each method including cost and risk reduction as well as sensitivity to cleanup levels and time constraints.

The subcommittee will identify the greatest needs in the focus area and the reasons for identifying the technologies being developed. It should identify the difficulties in bringing the technologies being developed to fruition. The subcommittee will further address potential for industrial applications and pay-offs of the technologies being developed to DOE and industry, including foreign markets. The subcommittee should also identify new technologies which have scope for development. It should recommend actions as to what else should be done and how to accelerate the process. This information should be presented as a report to the parent committee.

The subcommittee as a whole, or its members separately, will visit representative DOE Weapons Complex facilities to get first hand information and interact with scientists working at the sites.

Topical reports as indicated above, as appropriate, and minutes of the subcommittee meetings, will be submitted as inputs to the work of CEMT. The subcommittee chairman will provide an annual report to CEMT on December 1st every year.

SUBCOMMITTEE ON MIXED WASTES

Statement of Task

The Subcommittee on Mixed Wastes is established with a view to assist the Committee on Environmental Management Technologies (CEMT) as one of the five major focus areas.

The subcommittee will review the DOE documentation including (1) DOE's Remedial Action Program Information Center (RAPIC) bibliography, (2) EPA's Cleanup Information (CLU-IN), (3) Vendor Information System for Innovative Treatment Technologies (VISITT), and (4) Alternative Treatment Technology Information Center (ATTIC) Bulletin Board. The subcommittee also will review the pertinent technical literature and consult with experts in the field to ensure that state-of-the-art documentation is available on the different technical issues and developments involved in mixed wastes characterization, treatment, and disposal. If not already available, the subcommittee shall prepare a report including the advantages and disadvantages of each method including cost and risk reduction as well as sensitivity to cleanup levels and time constraints.

The subcommittee will identify the greatest needs in the focus area and the reasons for identifying the technologies being developed. It should identify the difficulties in bringing the technologies being developed to fruition. The subcommittee will further address potential for industrial applications and pay-offs of the technologies being developed to DOE and industry, including foreign markets. The subcommittee should also identify new technologies which have scope for development. It should recommend actions as to what else should be done and how to accelerate the process. This information should be presented as a report to the parent committee.

The subcommittee as a whole, or its members separately, will visit representative DOE Weapons Complex facilities to get first hand information and interact with scientists working at the sites.

Topical reports as indicated above, as appropriate, and minutes of the subcommittee meetings, will be submitted as inputs to the work of CEMT. The subcommittee chairman will provide an annual report to CEMT on December 1st every year.

Appendix C

Biographical Sketches of Committee and Subcommittee Members

BAISDEN, Patricia A.—Dr. Baisden received her B.S. in 1971, and her Ph.D. in chemistry in 1975 from Florida State University. Her research interests focus on measurement of heavy-element fission properties using both chemical and on-line techniques, solution chemistry of lanthanide and actinide elements, and heavy-ion collisions leading to complete or incomplete fusion. Since 1981, Dr. Baisden has worked for the Lawrence Livermore National Laboratory in Livermore, California. She is currently a Division Leader in Chemistry & Materials. Her expertise is in nuclear chemistry and radiochemistry, inorganic and analytical chemistry, and actinide chemistry. Dr. Baisden's memberships include the American Physical Society, the American Chemical Society, and Sigma Xi.

BAUGH, Kent D.—Dr. Baugh earned a Ph.D. in environmental engineering in 1983. Since 1991, he has been employed at OHM Remediation Services Corporation, where he is manager for technical services. In addition, he has 18 years' experience in management design, construction, and operation of remedial actions for a wide variety of contaminants, including metals, PCBs, pesticides, VOCs, POL, radionuclides, and acid/bases. His remediation experience includes design and implementation of in-situ and ex-situ remediation treatment technologies.

BEDIENT, Philip E.—Dr. Bedient received a B.S. in physics, an M.S. in environmental engineering, and a Ph.D. in environmental engineering sciences from the University of Florida. His research interests include computer modeling of contaminant transport in surface and ground water systems, and the development of decision support systems for site remediation. Dr. Bedient is currently a professor and Chair of the Department of Environmental Engineering at Rice University, Houston, Texas. He held the Shell Distinguished Chair in Environmental Science from 1988-1993 and directed the development and application of the BIOPLUME II program for modeling aerobic biodegradation of organic contaminants in ground water. Dr. Bedient has written over 100 articles and co-authored three textbooks.

BIER, Vicki M.—Dr. Bier earned her B.S. from Stanford University in 1976 and her Ph.D. from the Massachusetts Institute of Technology in 1983. Her specialties include operations research and risk assessment. Dr. Bier is an associate professor in the Department of Industrial Engineering and the Department of Nuclear Engineering & Engineering Physics at the University of Wisconsin, where she has been since 1989. From 1982 to 1989 she worked in risk assessment of nuclear power plants for Pickard Lowe & Garrick, Inc. Dr. Bier's memberships include the Institute for Operations Research and Management Science and the Society for Risk Analysis. Her research interests focus on operations research and the treatment of uncertainty in estimation and decision making.

BROWN, Kirk W.—Dr. Brown has a B.S. from Delaware Valley College, an M.S. from Cornell University, and a Ph.D. from the University of Nebraska. His research has focused on the land disposal of wastes and the cleanup of sites contaminated with agricultural and industrial chemicals. Dr. Brown has written several books and over 175 technical articles. He is currently a professor of soil science at Texas A&M University in College Station and is also a member of the faculty of toxicology. In 1981, Dr. Brown founded an environmental science and engineering consulting firm, and he now serves a consultant through K.W. Brown Environmental Services. He has served on several EPA, Office of Technology Assessment, and National Research Council committees. He has received numerous awards from Texas A&M University and from his professional societies.

BURSTEIN, Sol—Dr. Burstein received a B.S.M.E. degree from Northeastern University and a D.Sc. (hon) from the University of Wisconsin at Milwaukee. He is a registered professional engineer and member of the National Academy of Engineering. He retired in 1987 as Vice Chairman of the Board of Directors of Wisconsin Energy Corporation, the holding company for Wisconsin Natural Gas Company and Wisconsin Electric Power Company, of which he also served as Vice President and Director. His career with Wisconsin Electric spanned 21 years, prior to which he spent over 19 years in engineering design and construction work at Stone & Webster. He currently is an independent consultant specializing in utility management and nuclear and mechanical engineering. He has served on numerous industry and government advisory committees and is a member of the National Research Council's Board on Radioactive Waste Management.

BYRD, Joseph S.—Professor Byrd received his B.S. and M.S. in Electrical Engineering from Clemson University and the University of South Carolina, respectively. He joined the faculty of the University of South Carolina in 1989 and is currently Professor of Electrical and Computer Engineering. For the previous 28 years he held various positions at the DuPont Savannah River Laboratory, Aiken, South Carolina, where he managed the Engineering Development Group, organized and managed the Robotics Technology Group that realized the first robotics applications at the Savannah River Site, and conducted and managed R&D in mobile robotics. His professional activities include South Carolina Society of Professional Engineers, Robotics and Remote Systems Division of the American Nuclear Society (past Chair), Editorial Advisory Board for *RadWaste Magazine*, and a previous member of the Waste Management External Advisory Committee and Single-Shell Tank Retrieval Technology Panel (organizer and Chair) for Westinghouse Hanford Company. His current research is in the area of mobile robotics. He is Principal Investigator and Project Manager for an autonomous inspection robotic system for stored low-level radioactive waste. In addition to his research, Mr. Byrd has received two teaching awards. He has made numerous presentations as well as written many publications on robotics and computer technology. He is also co-author of a textbook on computer architecture. Professor Byrd has received two teaching awards.

CARTER, Melvin W.—Dr. Carter received his B.S. degree in civil engineering, his M.S. in public health engineering from the Georgia Institute of Technology, and, his Ph.D. in radiological health from the University of Florida. He is Neely Professor Emeritus of Nuclear Engineering and Health Physics at the Georgia Institute of Technology in Atlanta. He specializes in public health engineering and radiation protection. Before joining the faculty at Georgia Institute of Technology, he had extensive experience in radiological health with the U.S. Public Health Service and the EPA. He served as director of several major government laboratories, including the National Environmental Research Center in Las Vegas (1968-1972). Dr. Carter is a former President of the International Radiation Protection Association and the Health Physics Society. He serves and has served on numerous advisory committees and boards, including the National Research Council's Board on Radioactive Waste Management. He is an Honorary Member of the National Council on Radiation Protection and Measurements and serves as Chairman Emeritus of its Scientific Committee 64 on Environmental Issues. Dr. Carter continues to consult with international agencies, governmental organizations, businesses, and industry.

CLARKE, Ann N.—Dr. Clarke holds Masters degrees from Johns Hopkins University in chemistry and earth sciences and a Ph.D. from Vanderbilt University in chemistry with a minor in environmental engineering. Currently, she is Director of the Remedial Technologies Development Division for ECKENFELDER INC., Nashville, Tennessee. Her areas of expertise include Part B permitting, RCRA compliance training, environmental fate and transport of chemicals, development sampling and analysis programs for trace level organics, mathematical modeling, and Phase I Assessments and Compliance Audits throughout the United States and abroad. She directed multiple activities under contract to the USEPA-CERI program, served as a Director of the National Environmental Training Association and was 1989 Educator of the Year, and currently serves on the Scientific Review Panel for the National Library of Medicine's Hazardous Substances Data Bank. For the last decade, Dr. Clarke has directed research on the design and development of innovative technologies for the remediation of soil, ground water, and air at hazardous waste sites. Dr. Clarke is the author of over 100 technical reports, papers, and books.

CLEMENS, Bruce W.—Mr. Clemens is currently a member of the Energy, Environment, and Resources Center at the University of Tennessee, Knoxville, where he is leading a task to establish standards for radioactive scrap metal. His current research efforts focus on how organizations address environmental initiatives. Mr. Clemens has managed major, multimillion dollar environmental programs around the world. While with the U.S. Environmental Protection Agency, Mr. Clemens was responsible for the first guidance on Remedial Investigations and Feasibility Studies. Mr. Clemens has acted as a consultant for federal, state, and international organizations. He has served on various national and international task forces on subjects including hazardous-waste management, disaster relief assistance, and public water supply, and has served as a technical expert in court cases.

CONWAY, Richard A.—Mr. Conway earned his B.S. at the University of Massachusetts and his M.S. in civil engineering at the Massachusetts Institute of Technology. In 1954, Mr. Conway began his career in the U.S. Army as an assistant preventive medical officer, and in 1957, he joined Union Carbide Corporation as a development engineer, where he is now a Senior Corporate Fellow. He has received many honors and awards, such as the Hering Medal, Gascoigne Medal, Dudley Medal, Rudolfs Medal and honors from the American Society of Civil Engineers and the American Society for Testing and Materials. Mr. Conway is a member of the National Academy of Engineering, American Society of Civil Engineers, the Water Environment Association, Sigma Xi, Association of Engineering Professors, Society for Environmental Toxicology and Chemistry, and the American Academy of Environmental Engineers. His research interests include, contaminated site remediation, hazardous waste management, and risk analysis related to chemicals in the environment.

COTTON, Thomas A.—Dr. Cotton received a B.S. in electrical engineering from Stanford University, an M.S. in philosophy, politics, and economics from Oxford University, and a Ph.D in engineering-economic systems from Stanford University. He is vice president of JK Research Associates, Inc. where he is a principal in activities related to radioactive-waste-management policy and strategic planning. Before joining JK Research Associates, he dealt with energy policy and radioactive-waste-management issues as an analyst and project director during nearly 11 years with the Congressional Office of

Technology Assessment. His expertise is in public policy analysis, nuclear waste management, and strategic planning.

CRIMI, Frank, P.—Mr. Crimi completed a B.S. in mechanical engineering at Ohio University in Athens in 1951, and did graduate studies in mechanical engineering at Union College, Schenectady, New York, from 1957 to 1959. He has been employed in the Environmental Management Division of Lockheed Martin Environmental Systems since 1992. Mr. Crimi has 33 years of experience and maintenance of DOE naval nuclear reactor plants with special emphasis in decontamination and decommissioning of nuclear plants and facilities. He was the General Electric project manager for the Shippingport Atomic Power Station decommissioning. He chaired the Long Island Power Authority's independent review panel during the decommissioning of the Shoreham Nuclear Power Station and is a member of the public service of Colorado's Management Oversight Committee for the Fort Saint Vrain Nuclear Generating Station decommissioning.

CROFF, Allen G.—Mr. Croff has a B.S. in chemical engineering from Michigan State University, a nuclear engineering degree from the Massachusetts Institute of Technology, and an M.B.A. from the University of Tennessee. He is Associate Director of the Chemical Technology Division at Oak Ridge National Laboratory (ORNL). His areas of expertise include initiation and technical management of research and development involving waste management, nuclear fuel cycles, transportation, conservation, and renewable energy. Since joining ORNL in 1974, he has been involved in numerous technical studies on waste management and nuclear fuel cycles, and his duties have included supervising and participating in the updating, maintenance, and implementation of the ORIGEN-2 computer code; developing a risk-based, generally applicable radioactive-waste classification system; developing and assessing multidisciplinary studies of actinide partitioning and transmutation; and leading and participating multidisciplinary national and international technical committees.

DAVIS, Gary A.—Mr. Davis has a chemical engineering degree from the University of Cincinnati and a law degree from the University of Tennessee. He is the Director of the University of Tennessee Center for Clean Products and Clean Technologies, an interdisciplinary research center focusing on the earliest stages of pollution prevention. His research includes life-cycle environmental impacts of products, substitutes for polluting products, and policies to encourage the use of cleaner products and processes. The Center conducts research for the EPA, an environmental labeling organization, Green Seal, and other companies. Mr. Davis has been working on technical and policy issues related to pollution prevention and hazardous substance management for over 15 years. He is also an Adjunct Professor of Environmental Law at the University of Tennessee College of Law. Prior to his position at the Center, Mr. Davis was a hazardous-waste policy advisor with the California Governor's Office, and a practicing chemical engineer with an environmental consulting firm developing pollution-prevention technologies for industry.

DEJONGHE, Paul—After completing his undergraduate degree from Ghent University in 1949, Dr. Dejonghe received his doctorate degree in 1960. He is currently emeritus professor of Leuven University and general advisor to the chairman of the board of the nuclear research center at Mol, Belgium. During his career, he has served as member or chairman of several international committees on radioactive-waste management of Euratom/E.C., the OECD and IAEA. Dr. Dejonghe's professional career took place mainly at the Nuclear Research center at Mol, where he held positions in radioactive-waste management, and served as both assistant general manager and acting general manager. Simultaneously, he was part-time professor at the University of Leuven, Belgium, Faculty of Applied Sciences. He was a founding member of the company INDAVER for the management of hazardous wastes in the port-area of Antwerp.

de MARSILY, Ghislain—Dr. de Marsily graduated as a mining engineer from the Paris School of Mines in 1963 and received a Doctorate of Science in 1978 from the University of Paris. He has been professor of Applied Geology at the University of Paris VI since 1987 and is also professor at the Paris School of Mines. Dr. de Marsily was Head of the Hydrogeology group at the Paris School of Mines from 1973 to 1987. He is a member of the advisory group of the French Nuclear Safety Authorities, and of the National Committee for Evaluation of Research in Nuclear waste disposal. He has also served on advisory panels for geologic disposal at the European Commission, the Swedish Nuclear Power Inspectorate, the Swiss Paul Scherer Institute, and Sandia National Laboratories for the WIPP project.

DORNSIFE, William P.—Mr. Dornsife graduated from the U.S. Naval Academy in 1966. After his naval service, he received an M.S. degree in nuclear engineering from Ohio State University. He began working for the Pennsylvania Bureau of Radiation Protection in 1976 as a nuclear engineer, and then held the position of Chief of the Nuclear Safety Division. He was responsible for managing the Nuclear Safety Program and the Low-Level Radioactive Waste (LLRW) Program. Mr. Dornsife is currently the Director of the Pennsylvania Bureau of Radiation Protection. Mr. Dornsife is a registered professional engineer in the Commonwealth of Pennsylvania and participates nationally in a variety of LLRW and other radiation issues. He is an elected member of the National Council on Radiation Protection and Measurements (NCRP). He chairs the EPA NACEPT Subcommittee on Radiation Cleanup Regulation, and is a member of various National Research Council and USDOE oversight panels. He is a full member of the Conference of Radiation Control Program Directors (CRCPD) and serves on its Executive Board as Chairperson Elect.

DRUMMOND, Marshall E.—Dr. Drummond holds an M.B.A. in marketing and economics from San Jose State University, a B.S. in management from Colorado State University, a doctor of education degree in higher-education administration, organization, and leadership from the University of San Francisco. He has been president of Eastern Washington University since 1990. Dr. Drummond began service at Eastern Washington in the mid-1980's as vice president for administrative services and as executive vice president, responsible for all aspects of internal management at the university. He is a founding member of and was general manager of Technology Specialists, Inc. in Exton, Pennsylvania, 1985–1989. In 1992 he became chair of the Hanford Future Use Working Group. Dr. Drummond is a member of several national honor societies and has published many works in professional journals relating to his academic discipline and higher-education management.

EXNER, Jurgen H.—Dr. Exner received his BS degree from the University of Minnesota in 1963, and his Ph.D. at the University of Washington in 1968. He is the principal and president of JHE Technology Systems, Inc., a consulting firm he formed in 1992. Prior to that, he was senior vice president, Technical Development and Analytic Services, OHM Corporation, and held various positions with OHM Corporation, IT Corporation, IT, Environscience, Hydrosciences, and Dow Chemicals. He is a member, and Chair, Division of Environmental Chemistry, of the American Chemical Society. From 1986–1988, Dr. Exner was a lecturer for the Environmental Protection Agency Seminar on

RCRA/CERCLA, and has participated in many national and international conferences and workshops. Dr. Exner holds numerous patents. He is also the Associate Editor of the *Journal of the Air and Water Control Federation*.

FJELD, Robert A.—Dr. Fjeld holds a Ph.D. in nuclear engineering from the Pennsylvania State University. He is currently the Dempsey Professor of Waste Management in the Department of Environmental Systems Engineering at Clemson University, where he coordinates a graduate-level program on the environmental aspects of nuclear technologies. His research efforts are focused on environmental restoration and waste-management activities, and he has done consulting in operational health physics, risk assessment, radioactive decontamination and aerosol filtration. Dr. Fjeld is active in the American Society of Mechanical Engineers (ASME) Mixed Waste Committee, serving as Chairman of the Education/Information Subcommittee, and is a member of the Health Physics Society and the American Nuclear Society.

FOUNTAIN, John C.—Dr. Fountain completed his Ph.D. in geology at the University of California in Santa Barbara in 1975. He joined the faculty of the State University of New York, Buffalo, in 1975. Currently, he is an associate professor of geology there—a position he has held since 1980. As a geochemist, Dr. Fountain's research has focused on contaminant hydrology, specifically aquifer remediation and characterization of fractured rock aquifers. He is a member of the Geological Society of America, the American Geophysical Union, and the National Ground Water Association.

GARRICK, B. John—Dr. Garrick received his Ph.D. in engineering and applied science from the University of California, Los Angeles, and is a graduate of the Oak Ridge School of Reactor Technology. He is Chairman of PLG, Inc., an international engineering, applied science, and management consulting firm. Dr. Garrick is a member of the National Academy of Engineering and is a Fellow of the American Nuclear Society, the Society for Risk Analysis, and the Institute for the Advancement of Engineering. He is Vice-Chair of the National Research Council's Board on Radioactive Waste Management. In 1993, Dr. Garrick was appointed to the U.S. Nuclear Regulatory Commission's Advisory Committee on Nuclear Waste, of which he is now the Vice Chairman. He is a past president of the Society for Risk

Analysis, an international society, and in 1994, received that society's highest honor, the Distinguished Achievement Award, for his contribution to the science of risk analysis. Dr. Garrick has published approximately 200 papers and reports on risk, reliability, engineering, and technology.

GULAS, Victor G.—Dr. Gulas completed his Ph.D. in sanitary engineering at Virginia Polytechnic Institute & State University. He is a senior vice president at Montgomery Watson, in Boulder, Colorado, in charge of innovation and technology for the company's industrial/hazardous waste operations. His experience includes design and research work in biological processes, such as activated sludge, aerobic and anaerobic digestion; trickling filters; and waste-stabilization ponds with physical-chemical processes. He has served as project manager for the process development of a wastewater treatment plant upgrade for a major chemical manufacturer, principal-in-charge of a large remedial investigation/feasibility study for an 880-acre abandoned refinery site in Louisiana, project manager third-party oversight of a PCB-contaminated underground cleanup at the Savannah River Plant in South Carolina, and project manager on a remedial action plan for a dump site containing 100 to 200 55-gallon drums. Dr. Gulas also managed an industrial wastewater treatment process development and directed the predesign of three industrial wastewater treatment plants.

KINTNER, Edwin E.—Mr. Kintner received a B.S. from the U.S. Naval Academy and an M.S. in nuclear physics and in marine engineering, from MIT. He was executive vice president of General Public Utilities (GPU) Nuclear Corporation and member of its Board of Directors for seven years until his retirement in June 1990. During that time, he was the corporate official responsible for the cleanup of the TMI-2 reactor accident. His background includes many years of nuclear reactor experience both with the military and private industry. He was chair of the Nuclear Power Division Advisory Committee and chair of the Advanced Light Water Reactor Utility Steering Committee, which reconceptualized the next generation of reactors. In addition, he was a member of the Massachusetts Institute of Technology's Corporation Visiting Committee for Nuclear Engineering. He is a member of the National Academy of Engineering and the American Nuclear Society. Mr. Kintner chaired the National Research Council's Transmutation Subcommittee four-year study of Separations and Transmutation of Radioactive Wastes. Prior to joining GPU, he was director of the U.S.

Magnetic Fusion Program at the USDOE and its predecessor agency. In previous years, he was assistant director for reactor engineering and then deputy director of the former Atomic Energy Commission's Reactor Development Division. Among awards received during his career are the Secretary of the Navy Commendation Medal, the title of Distinguished Alumnus of MIT, and the highest award of the Senior Executive Service. Mr. Kintner represented the United States as chair of the U.S./U.S.S.R. Joint Fusion Power Coordinating Committee and chair of the U.S/Government of Japan Fusion Power Coordinating Committee.

MYERS, Peter B.—Dr. Myers served in World War II with the U.S. Navy before completing his doctorate in nuclear physics as a Rhodes Scholar at Oxford University. He retired in 1993 after 14 years as director of the National Research Council's Board on Radioactive Waste Management. Dr. Myers has held management positions with responsibility for research and development of advanced solid-state technology at Bell Telephone Laboratories, Motorola, the Martin Company, Bunker Ramo, and Magnavox. Dr. Myers is a fellow of both the Institute of Electrical and Electronic Engineers, and the American Association for the Advancement of Science. He was a founding member of the Institute of Management Sciences and is a member of the American Nuclear Society, the American Physical Society, and the Materials Research Society.

PARKER, Frank L.—Dr. Parker received his B.S. from the Massachusetts Institute of Technology and Ph.D. from Harvard University. He is a Distinguished Professor of Environmental and Water Resources Engineering at Vanderbilt University, where he has been a professor since 1967. He also serves as the Westinghouse distinguished professor at Clemson University. He is a member of the American Geophysical Union, the American Nuclear Society, the Society for Risk Analysis, the Health Physics Society, and the American Association for the Advancement of Science. Dr. Parker is a senior researcher at the International Institute for Applied Systems Analyses and is a member of several environmental advisory committees, including the Environmental Management Advisory Board of the Department of Energy. Dr. Parker is a member of the National Academy of Engineering, and chaired the National Research Council's Committee on Environmental Management Technologies from its inception in 1994 to September 1995. Formerly, he was the Chairman of the

National Research Council's Board on Radioactive Waste Management.

PARSHALL, George W.—Dr. Parshall received his B.S. in chemistry from the University of Minnesota in 1951 and his Ph.D. in organic chemistry from the University of Illinois in 1954. He was Director of Chemical Science in the Central Research & Development Department of the DuPont Company from 1979 until his retirement at the end of 1992. He started work as a research chemist in the Department in 1954 and was promoted to Research Supervisor in 1965 where he was in charge of a group in organometallic chemistry and homogeneous catalysis until 1979. Since retirement, he has consulted for DuPont and has been involved in a number of advisory activities through the National Research Council. Dr. Parshall is a member of the National Academy of Sciences and of the American Academy of Arts and Sciences. He received two major American Chemical Society Awards: the ACS Award in Inorganic Chemistry, and the Barnes Award for Leadership in Chemical Research Management. He has published two books.

POHLAND, Frederick G.—Dr. Pohland received his B.S. in civil engineering from Valparaiso University and, after a period of employment as an engineer with the Erie Railroad Company, completed military service with the U.S. Army and graduate studies at the M.S. and Ph.D. levels in environmental engineering at Purdue University. His research has focused on environmental engineering operations and processes, solid-and hazardous waste management, and environmental impact monitoring and assessment. Dr. Pohland began his career at the Georgia Institute of Technology, and most recently, at the University of Pittsburgh, where he is Professor and Edward R. Weidlein Chair of Environmental Engineering. In addition to his academic appointments, Dr. Pohland has been a Visiting Scholar at the University of Michigan and a Guest Professor at the Delft University of Technology in The Netherlands. Some of his memberships include the National Academy of Engineering, American Water Works Association, Water Environment Federation, American Chemical Society, and the International Association on Water Quality. He is a Diplomate and Past President of the American Academy of Environmental Engineers.

PRESLO, Lynne M.—Ms. Preslo holds an M.S. in hydrogeology from Stanford University. Currently, she is the Senior Vice President for Technical Programs at Earth Tech in Berkeley, California. Prior to Earth Tech, she held the position of vice president for the earth-science practice of ICF-Kaiser Engineers. During the last eight years, she has served as the principal hydrogeologist and project director on five major ground-water remediation projects in California and co-authored a book on in-situ and ex-situ remedial technologies. She also served on an expert advisory panel regarding ground-water and soil cleanup policies, perspectives, and future trends for the Environmental Protection Agency's Office of Research and Development. Ms. Preslo served as a member of the National Research Council's Committee on Ground-Water Cleanup Alternatives.

ROBERTS, Paul—Dr. Roberts received a B.S. in chemical engineering from Princeton University in 1960, an M.S. in environmental engineering from Stanford University in 1971, and a Ph.D. in chemical engineering from Cornell University in 1966. He is currently a professor of environmental engineering at Stanford University and researches contaminant transport in porous media. Previously, he headed the Engineering Department of the Swiss Federal Institute of Water Supply and Water Pollution Control. Also, he has worked as a research engineer at Stanford Research Institute and a process engineer at Chevron Research Company.

ROGERS, Vern C.—Dr. Rogers received his Ph.D. in nuclear engineering from the Massachusetts Institute of Technology in 1969. He also holds a B.S. degree in physics and an M.S. degree in mechanical engineering (nuclear) from the University of Utah in 1965. He received an M.B.A. from the University of Phoenix in 1992. He is President of Rogers and Associates Engineering Corp—a technical consulting company focusing on radioactive-and hazardous-waste management He is a Fellow of the American Nuclear Society and is a member of the Health Physics Society, the American Physical Society, and the American Institute of Chemical Engineers. Dr. Rogers also is a Certified Health Physicist and a Registered Professional Engineer. Prior to forming Rogers and Associates in 1980, he was Vice President and Manager of Nuclear and Advanced Programs at Ford, Bacon & Davis Utah, Inc. Dr. Rogers co-developed the analytical and laboratory methodology for designing and evaluating covers for impoundments of radium-containing wastes.

SOMBRET, Claude G.—Dr. Sombret was born and educated in Paris. He holds a Ph.D. in ceramics. Dr. Sombret joined the Commissariat à l'Energie Atomique (CEA) in 1957, where he held several positions until his retirement in 1994. Currently, Dr. Sombret is working as a consultant and resides in Villeneuve-Lès-Avignon, France. He has been involved in R&D in the field of waste management and has conducted research on the specification of the French nuclear waste glasses, as well as on processes of industrial interest dealing with high-level vitrification. One of these processes is now implemented in the French vitrification facilities at Marcoule (AVM) and at La Hague (R7 and T7) and at Sellafield, UK (WVP). He played a major role in the design of AVM and participated in the design of R7 and T7. Dr. Sombret has published articles in French, American, and British journals and has presented over fifty papers at various symposia. He is a member of many societies and associations including the American Nuclear Society, the American Ceramic Society, and the Materials Research Society.

STEINDLER, Martin J.—Dr. Steindler holds a Ph.D. in chemistry from the University of Chicago. He is currently a consultant for USDOE and USDOE laboratories. He has held membership in the Nuclear Regulatory Commission's Atomic Safety and Licensing Board Panel for the past 18 years. From 1953 to 1993, he worked as a chemist for Argonne National Laboratories, where he retired as the Director of the Chemical Technology Division. Dr. Steindler is also a member of the USNRC's Advisory Committee on Nuclear Waste where he was chairman from 1994-1995. Previously, he was a member of the waste-management subcommittee of the USNRC's Advisory Committee on Reactor Safeguards. He has authored over 130 papers and scientific reports, holds several patents, and has received many awards in his field.

THIBODEAUX, Louis J.—Dr. Thibodeaux is Jessie Coates Professor of Chemical Engineering at Louisiana State University. He served as Director of the Hazardous Substance Research Center South/Southwest until 1995 and was on the faculty of the University of Arkansas for sixteen years prior to returning to LSU where he received all three education degrees. In graduate school he held a National Council for Air and Stream Improvement fellowship. His teaching and research activities are concerned with the fate and transport of chemicals near environmental interfaces. Presently, his research focuses on contaminant release mechanisms from bed-sediments. In addition, he is a consultant for several organizations, government, private and academic, and has written a textbook.

TRAVIS, Curtis C.—Dr. Travis completed a Ph.D. in mathematics at the University of California, Davis, in 1971. He has been employed at Oak Ridge National Laboratory since 1976; currently, he is the Director of the Center for Risk Management in the Health Sciences Research Division. During his 10-year academic career, he served as a research engineer at the Jet Propulsion Laboratory at the California Institute of Technology and was assistant professor of mathematics at both Vanderbilt University and the University of Tennessee. Dr. Travis has served on several state and federal agencies' advisory groups and several National Research Council committees.

WARD, C. Herb—Dr. Ward has a B.S. from New Mexico State University and an M.S. and Ph.D. from Cornell University. He also earned an M.P.H. in environmental health from the University of Texas. Dr. Ward is the Foyt Family Chair of Engineering in the George R. Brown School of Engineering at Rice University. He is also Professor of Environmental Science and Engineering and Ecology and Evolutionary Biology. Dr. Ward is now Director of the Energy and Environmental Systems Institute (EESI) at Rice University. He is also the Director of the Department of Defense Advanced Applied Technology Demonstration Facility (AATDF). For the past 14 years he has directed the activities of the National Center for Ground-Water Research (NCGWR). He is co-director of the EPA-sponsored Hazardous Substances Research Center/South & Southwest (HSRC/ S&SW). Dr. Ward has served as president of both the American Institute of Biological Sciences and the Society of Industrial Microbiology, and is currently vice-president of the U.S. National Committee of the International Water Resources Association. He is the editor-in-chief of the international journal, *Environmental Toxicology and Chemistry*.

WATERS, Robert D.—Dr. Waters earned his B.S. in civil engineering from the University of Kentucky in 1983 and his Ph.D. in civil and environmental engineering from Vanderbilt University in 1993. He is a senior member of the technical staff at Sandia National Laboratories, primarily responsible for evaluating potential DOE sites for disposal of mixed low-level waste. He also has 7 years' experience in oil and gas production. Dr. Waters' research interests include technical and policy analysis for hazardous, radioactive, and mixed-waste disposal and assessment of environmental damage in the former Soviet Union. He is recipient of the NAS/NRC Collaboration in Basic Science and

Engineering (COBASE) and Collaborative Research in Sectoral Policy (CRSP) grants programs for research in the Ukraine.

WEBER, Walter J., Jr.—Dr. Weber completed a Ph.D. in environmental and water resources engineering at Harvard University in 1962. He is the Gordon M. Fair and Earnest Boyce Distinguished University Professor of Engineering in the Department of Civil and Environmental Engineering, the Director of the Great Lakes and Mid-Atlantic Hazardous Substance Research Center, and the Executive Director of the National Center for Integrated Bioremediation Research and Development Center at the University of Michigan in Ann Arbor. He has held various positions at the University of Michigan since 1963 and has served as a visiting professor both nationally and internationally. Since 1960, he has been a consultant to federal, state, and local governments, foreign, industry, and engineering firms. Dr. Weber's research focuses on phase separation technologies and process and transport modeling, ranging from fundamental concept development through the modeling and design of full-scale systems. He has authored or coauthored three books and approximately 300 technical publications. Dr. Weber is the recipient of numerous honors and awards and is a member of several national professional associations. He was elected to the NAE in 1985.

WENNERBERG, Linda—Dr. Wennerberg earned a Ph.D. in environmental law and resource economics from Michigan State University in 1984. Currently, she runs a private consulting practice applying 20 years' experience reviewing and developing environmental and economic policies with technical applications including a performance review of a federal toxic program; implementing radioactive and hazardous waste-management programs for state agencies; developing the draft-siting criteria process for low-level radioactive waste disposal; determining environmental enforcement priorities for oil and natural gas production; and identifying pollution prevention opportunities in manufacturing.

WYMER, Raymond G.—Dr. Wymer received his B.A. from Memphis State University and his M.A. and Ph.D. from Vanderbilt University. He retired as director of the Chemical Technology Division of Oak Ridge National Laboratory. He is a specialist in radiochemical separations technology for radioactive-waste management and nuclear fuel reprocessing. He is a consultant for ORNL and the USDOE in the area of chemical separations technology and for the U.S. Department of State and the USDOE on matters of nuclear nonproliferation. He is a fellow of the American Nuclear Society and the American Institute of Chemists and has received the American Institute of Chemical Engineers Robert E. Wilson Award in Nuclear Chemical Engineering and the American Nuclear Society's Special Award for Outstanding Work on the Nuclear Fuel Cycle.

Appendix D

Acronyms

AIBS	American Institute of Biological Sciences
APS	American Physical Society
ARAR	Applicable or Relevant and Appropriate Requirements
BEMR	Baseline Environmental Management Report
BES	Office of Basic Energy Sciences (DOE)
CEMT	Committee on Environmental Management Technologies
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
D&D	Decontamination and Decommissioning
DNAPL	Dense Nonaqueous Phase Liquids
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EM	Environmental Management
EO	Electrochemical Oxidation
ESP	Efficient Separations and Processing
FA	Focus Area
FASEB	Federation of American Societies for Experimental Biology

FFCA	Federal Facilities Compliance Act
FMS	Facility Mapping System
FY	Fiscal Year
GMODS	Glass Material Oxidation and Dissolution System
HER	Office of Health and Environmental Research (DOE)
HLW	High-Level Wastes
HWIR	Hazardous Waste Identification Rule
ICPP	Idaho Chemical Processing Plant
IDCS	Internal Duct Characterization System
INEL	Idaho National Engineering Laboratory
LDUA	Light Duty Utility Arm
LLW	Low-Level Wastes
LNAPL	Light Nonaqueous Phase Liquids
MACS	Mobile Automated Floor Characterization System
METC	Morgantown Energy Technology Center
MLLW	Mixed Low-Level Waste
MTRU	Mixed Transuranics
MWFA	Mixed Waste Focus Area
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NDA	Non-Destructive Assay
NDE	Non-Destructive Evaluation
NIH	National Institutes of Health
NRC	National Research Council
NSF	National Science Foundation
OER	Office of Energy Research (DOE)
ORNL	Oak Ridge National Laboratory
OSHA	Office of Safety and Health Administration

OST	Office of Science and Technology (in DOE-EM)
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RTDP	Robotics Technology Development Program
SARA	Superfund Amendments and Reauthorization Act (1986)
SCWO	Supercritical Water Oxidation
SERS	Selective Equipment Removal System
SPCS	Small Pipe Characterization System
STATS	Committee on Separations and Transmutation Systems (NRC)
STCG	Site Technology Coordination Group
STP	Site Treatment Plan
TCE	Trichlorethylene
TRU	Transuranic (wastes/elements)
TRUEX	Transuranic Extraction
USDOE	U.S. Department of Energy
USEPA	U.S. Environmental Protection Agency
USNRC	U.S. Nuclear Regulatory Commission
VETEM	Very Early Time Electromagnetic