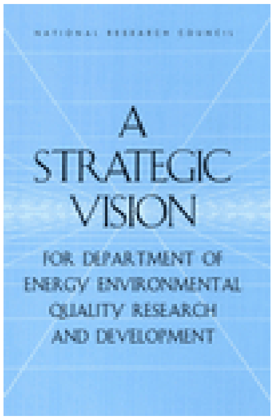

A Strategic Vision for Department of Energy Environmental Quality Research and Development

Committee on Building a Long-Term Environmental Quality Research and Development Program in the Department of Energy, Board on Radioactive Waste Management, National Research Council

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A STRATEGIC VISION

FOR DEPARTMENT OF ENERGY ENVIRONMENTAL QUALITY RESEARCH AND DEVELOPMENT

Committee on Building a Long-Term Environmental Quality Research and Development Program in the Department of Energy
Board on Radioactive Waste Management
Division on Earth and Life Studies
National Research Council

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BOARD ON RADIOACTIVE WASTE MANAGEMENT

Preface

The U.S. Department of Energy (DOE) is responsible for addressing a host of environmental problems associated with radioactive, hazardous, and mixed low-level wastes, nuclear materials, spent nuclear fuels, and contaminated lands, waters, and buildings[1] at over a hundred sites throughout the United States. DOE estimates that the nation will spend over $200 billion to remediate, manage, and dispose of these wastes and contaminated media over the next 70 years (DOE, 2000e). Even after many contaminated sites have been "cleaned up" in accordance with applicable regulations, residual risks to human health and the environment will remain at most DOE sites for centuries, if not millennia, and therefore will require some form of long-term stewardship (DOE, 1999a; NRC, 2000a). DOE currently spends approximately $6.7 billion a year on activities to manage and dispose of wastes and contaminated media throughout the DOE complex (see Sidebar 2.1 for description of the DOE complex). These activities are termed DOE's Environmental Quality (EQ) business line.[2]

Approximately 4 percent of DOE's EQ business line budget is spent on research and development (R&D) activities to improve scientific understanding and develop new approaches to address EQ problems. Since 1998, DOE has referred to these activities as its EQ R&D portfolio. The first comprehensive description of the portfolio was published in February 2000 (DOE, 2000b). In compiling this description, DOE recognized that its EQ R&D portfolio "may be under invested to sustain achievement of existing mission objectives beyond the near term, i.e.,

[1] The committee refers to these diverse types of waste, spent fuels, nuclear materials, and contaminated media collectively as "DOE wastes and contaminated media" (see Sidebar 1.1).

[2] EQ is one of DOE's four programmatic business lines. The other three programmatic business lines are Energy Resources, National Nuclear Security, and Science (see discussion in Chapter 1). The four programmatic business lines are supported by a corporate management function, which DOE's most recent strategic plan refers to as a fifth business line (DOE, 2000f).

beyond 2006" (DOE, 2000b, p. xiii).[3] This recognition prompted the Under Secretary of DOE to ask the National Academies' National Research Council (NRC) to provide advice on how DOE's EQ R&D portfolio could broaden its current short-term focus to include a more long-term, strategic view.

The committee was asked to address the following four questions, focusing on post-2006 R&D:

1. In the context of EQ strategic goals and mission objectives, what criteria should be used to evaluate the adequacy of the portfolio?
2. Using these criteria, what should be the principal elements of the portfolio?
3. Should the portfolio be designed to address environmental problems outside DOE (e.g., Department of Defense, Russia) that are related to EQ strategic goals?
4. How to determine the level of future investments in EQ R&D?

These questions differ from many NRC task statements in that they focus on high-level R&D management issues rather than detailed questions about a specific scientific or technical issue. Taken together, the answers to these four questions constitute the committee's views of how DOE's EQ R&D efforts can be made more effective by focusing more explicitly on DOE's most challenging EQ problems, i.e., a "strategic vision for DOE EQ R&D." The task statement also is unusual for the NRC because it asks for advice related to R&D funding levels. In particular, the committee was asked to provide advice on how to determine the level of future EQ R&D investments. It is important to recognize, however, that the committee was not asked to recommend a level of funding, nor to comment on whether the current level is too high or too low.

The task did not call on the committee to conduct a detailed evaluation of the existing EQ R&D portfolio. Such an analysis was conducted last year by DOE's Strategic Laboratory Council (referred to throughout the report as the "adequacy analysis" and summarized in Appendix C). This report complements and builds on the results of the adequacy analysis and also relies strongly on recent analyses of parts of the EQ R&D portfolio that have been carried out by other NRC committees (see annotated bibliography in Appendix F) and other review groups.

This study could not have been completed without the assistance of many individuals and organizations. The committee wishes to thank the many DOE staff members in the Office of Environmental Management; the Office of Civilian Radioactive Waste Management; the Office of Nu

[3] The portfolio's short-term emphasis has been confirmed by two subsequent analyses of DOE's EQ R&D portfolio (DOE, 2000g,h).

clear Energy, Science and Technology; and the Under Secretary's office for their active participation in committee meetings and in responding to requests for information. The committee is especially grateful to Gerald Boyd, who served as DOE's primary contact for this study, and his staff, particularly Mark Gilbertson, Jef Walker, Ker-Chi Chang, and Lana Nichols.

The committee expresses its deep appreciation to everyone who participated in the committee's two-day workshop in August 2000 (see Appendix B). The diverse mix of participants from DOE (headquarters and the sites), other agencies, national laboratories, academia, nongovernmental organizations, and the private sector contributed to lively discussions that provided great insights into the committee's task. The committee is grateful to speakers Jack Gibbons, David Heyman, James Owendoff, and Ivan Itkin, who helped set the stage for the workshop discussions.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remains confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

John F.Ahearne, Sigma Xi and Duke University

John Applegate, Indiana University School of Law

Allen G.Croff, Oak Ridge National Laboratory

James Economy, University of Illinois

John Fischer, U.S. Geological Survey (retired)

John C.Fountain, State University of New York at Buffalo

Thomas Leschine, University of Washington

Alexander MacLachlan, E.I.DuPont de Nemours & Company (retired)

John Pendergrass, Environmental Law Institute

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Michael Kavanaugh (Malcolm Pirnie, Inc.) and Paul Barton (U.S. Geological Survey, retired). Appointed by the NRC, they were responsible for making certain that an independent examination of this report was car

ried out in accordance with NRC procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

Finally, the committee thanks the NRC staff who assisted the committee throughout the study. Latricia Bailey provided very strong administrative support in all phases of the study, especially during committee meetings and in the preparation of the report. Suzanne Pessotto was instrumental in ensuring the success of the committee's summer workshop by doing an exceptional job handling all of the logistical challenges. Susan Mockler provided research support and prepared meeting minutes. Jennifer Nyman, a summer intern with the Board on Radioactive Waste Management, assisted in information gathering activities early in the study. Kevin Crowley, director of the Board on Radioactive Waste Management, provided helpful strategic advice to the committee. Gregory Symmes, the study director, was of invaluable assistance to the committee in preparation for and during the workshop and the other meetings and in turning committee members' writing into a cohesive and effective report.

Gregory R.Choppin

Chair

Contents

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is responsible for a diverse range of radioactive, hazardous, and mixed low-level wastes; nuclear materials; spent nuclear fuels; and contaminated lands, waters, and facilities (hereafter referred to collectively as "DOE wastes and contaminated media"). These wastes and contaminated media present the following general scientific, technical, and social challenges that will endure long into the future (this list of challenges, which was developed by the committee, is discussed more fully in Chapter 2):

- Remediate (i.e., "clean up") DOE sites[1] and facilities that have severe radioactive and hazardous waste contamination from past activities.
- Manage, stabilize, process, and dispose of a legacy of widely varying and often poorly characterized DOE wastes (including spent nuclear fuels and nuclear materials treated as waste) that are potential threats to health, safety, and the environment.
- Provide effective long-term stewardship[2] of DOE sites that have been remediated as well as currently practical, but that have residual risks to health, safety, and the environment.
- Develop, open, and operate unique, first-of-a-kind facilities for the permanent disposal of radioactive spent fuels and high-level wastes—many of which will be hazardous for thousands to hundreds of thousands of years.
- Limit contamination and materials management problems, including the generation of wastes and contaminated media, in ongoing and future DOE operations.

DOE currently spends approximately $6.7 billion a year to address

[1] See Sidebar 2.2 for a description of the largest DOE sites.

[2] DOE defines long-term stewardship as "all activities necessary to ensure protection of human health and the environment following completion of cleanup, disposal, or stabilization at a site or a portion of a site."

these challenges through the activities of its Offices of Environmental Management (EM) and Civilian Radioactive Waste Management (RW), and some programs within the Offices of Nuclear Energy, Science and Technology (NE) and Fissile Materials Disposition. DOE refers to the activities addressing these challenges collectively as its Environmental Quality (EQ) "business line."[3] Approximately 4 percent of the total EQ business line budget, or $298 million is spent on research and development (R&D) designed to support the EQ business line. DOE refers to these R&D activities collectively as its "EQ R&D portfolio."

The National Academies' National Research Council undertook this study in response to a request from the Under Secretary of Energy to provide strategic advice on how DOE could improve its EQ R&D portfolio. In particular, the committee was asked to address the following four questions, focusing on post-2006 R&D:

1. In the context of EQ strategic goals and mission objectives, what criteria should be used to evaluate the adequacy of the portfolio?
2. Using these criteria, what should be the principal elements of the portfolio?
3. Should the portfolio be designed to address environmental problems outside DOE (e.g., Department of Defense, Russia) that are related to EQ strategic goals?
4. How to determine the level of future investments in EQ R&D?

SCOPE OF DOE'S EQ MISSION

It is important to discuss the scope of DOE's EQ mission because any consideration of the adequacy of an R&D portfolio requires a clear understanding of the programmatic objectives that these R&D activities are intended to support. Such clarity is a challenge, however, because DOE's use of the term "environmental quality" is a misnomer that creates a great deal of confusion, both within and outside DOE, and because DOE documents reviewed by the committee are not entirely consistent in describing the EQ mission. The committee discusses the following three aspects of this issue: (1) its topical breadth (i.e., whether it includes, or should be broadened to include, environmental issues beyond wastes and contaminated media); (2) its temporal breadth (i.e., whether it should focus more explicitly on longer-term problems); and (3) its national and international breadth (i.e., whether its responsibilities should be extended to problems outside DOE, such as those in other agencies or nations).

[3] EQ is one of DOE's four programmatic business lines (the others are Energy Resources, National Nuclear Security, and Science). The programmatic business lines are supported by a corporate management function, which DOE's 2000 strategic plan refers to as a fifth business line.

The EQ R&D portfolio currently has a large number of important R&D opportunities and gaps, especially in areas requiring long-term R&D.[4] The committee believes that it would be inappropriate to consider expanding the topical breadth of the EQ mission until the R&D portfolio adequately addresses these gaps and opportunities. Furthermore, expanding the topical breadth of DOE's EQ mission to include all areas of the environment, such as sustainable development and global environmental protection, would create significant overlap with DOE's other missions (in particular, the Energy Resources and Science missions), as well as the missions of other federal agencies with longstanding environmental responsibilities. **For these and other reasons discussed in Chapter 2, the committee concludes that the EQ mission should continue to focus on problems associated with DOE wastes and contaminated media.** However, this conclusion does not lessen the importance of closely coordinating EQ R&D with related R&D efforts by DOE's other business lines.

One of the most consistent and important findings of recent studies of the EQ R&D portfolio is that it lacks a long-term strategic vision. The committee believes that this is due in part to the rather limited view of long-term EQ responsibilities in DOE's recent strategic plans (especially the 2000 plan). This short-term emphasis has provided a means for making progress on those aspects of the EQ mission for which technologies exist, but has done much less to address DOE's long-term and most challenging EQ problems,[5] such as those associated with the treatment and disposal of high-level radioactive waste and long-term stewardship. This emphasis also may have been misinterpreted by some decision makers to mean that the EQ mission, and particularly its R&D requirements, will be largely completed by 2006 or 2010. This "going out of business within the next decade" view has served to obscure the reality of DOE's long-term EQ responsibilities. **The committee recommends that DOE develop strategic goals and objectives for its EQ business line that explicitly incorporate a more comprehensive, long-term view of its EQ responsibilities.** For example, these goals and objectives should emphasize long-term stewardship and the importance of limiting contamination and materials management problems, including the generation of wastes and contaminated media, in ongoing and future DOE operations.

DOE asked the committee to consider whether the R&D portfolio should address environmental problems outside of DOE that are related

[4] Throughout this report the committee uses the term "short-term" to mean 5 years or less, and "long-term" to mean greater than 5 years.

[5] The term "EQ problems" refers to the set of technical problems that collectively make up the scientific and technical challenges described earlier. This is a useful concept in planning an R&D portfolio because the challenges are very broad, and must be broken down into manageable parts to be addressed by R&D.

to EQ strategic goals. **The committee concludes that it is appropriate for the EQ R&D portfolio to address environmental problems outside DOE if such R&D is directly related to DOE's EQ mission. At this time, however, the EQ R&D portfolio should not address environmental problems beyond DOE's jurisdiction that are unrelated to the EQ mission.** There may be cases in which spending limited R&D resources on problems outside DOE's EQ mission is appropriate, but deciding when this would be appropriate is less a technical question than a matter of general policy.

ADDRESSING LONG-TERM, CURRENTLY INTRACTABLE6 EQ PROBLEMS

Many of the problems confronting the EQ business line are longterm, both because they involve materials that remain hazardous, in some cases, for thousands to hundreds of thousands of years and because they are so complex and unique that R&D may have to continue for decades to generate their solutions.[7] DOE is responsible for managing, removing (or isolating), and disposing of uniquely hazardous, chemically complex substances, such as spent nuclear fuel, liquid high-level radioactive wastes, nuclear materials, mixtures of hazardous and radioactive compounds, and a wide range of contaminated media (e.g., groundwater, soil, and nuclear production facilities). These activities must be carried out under a wide range of challenging and often unique circumstances. Environmental cleanup, waste management, and disposal activities will, of necessity, endure for generations and long-term stewardship at most DOE sites may continue indefinitely. The future should provide opportunities for continual improvements and possible breakthrough technologies that could greatly reduce risks to human health and the environment and costs to future generations. **The committee concludes that the uniqueness and complexity of DOE's EQ problems demand that the EQ R&D portfolio have a strong, if not dominant, long-term component. The committee recommends that DOE begin to devote an increasing fraction of its EQ R&D to long-term problems to ensure that an R&D portfolio dedicated to long term problems is in place within five years. The committee also recommends that DOE develop a strategic vision for its EQ R&D portfolio. This vision should provide the framework for developing the science and technology necessary to address EQ problems that**

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[6] The committee uses the term "currently intractable" to refer to problems for which there are no identified, acceptable solutions but for which long-term R&D could lead to such solutions.

[7] When the expression "long-term R&D" is used in this report, the committee means "long-term" from both of these perspectives.

extend beyond the present emphasis of short-term "compliance" and should incorporate the principle of continual improvement.

ADVANCING MORE INFORMED DECISION MAKING

Numerous decisions on environmental remediation, waste management, materials storage, and facility decommissioning involve complex technical issues for which there are only limited data and partial scientific understanding. These gaps in knowledge affect DOE's decisions on each of the EQ challenges listed above. It should be emphasized, however, that lack of technical information does not necessarily preclude effective decision making. There are a number of examples of long-term EQ challenges (e.g., long-term stewardship, and geological disposal) where current decisions should include consideration that technology and understanding can be expected to improve considerably during the timeframe of the challenge.

For residual contamination at closed legacy sites, for example, the system of long-term stewardship should not preclude future actions to address remaining risks to human health and the environment. The system should allow future decision makers to re-initiate active cleanup activities if and when future technologies improve to a point where it makes sense to address remaining risks, or when the understanding of the effects of DOE wastes and contaminated media on human health and the environment improve. For geological disposal of high-level wastes and spent nuclear fuel, DOE should pursue a phased approach that would allow changes to the disposal plans to improve operations, safety, schedule, or cost throughout the decades-long process of emplacement. Such a phased decision process also could be applied to other important long-term EQ problems. DOE's EQ R&D portfolio should support decision making by including R&D on technical alternatives in cases where existing techniques are expensive, inefficient, or pose high risks to human health or the environment, or where techniques under development have high technical risks.[8] **The committee concludes that the EQ R&D portfolio is critical to improving decision making and should be designed to help inform important DOE decisions, including support for technical alternatives in areas of high cost or high risk.**

[8] Technical risk is defined as "the probability that the technique or method fails to accomplish the goals and performance requirements set by policy or regulation."

CRITERIA TO EVALUATE THE ADEQUACY OF THE EQ R&D PORTFOLIO

The committee presents its analysis of the important functions of an effective strategic EQ R&D portfolio in Chapter 3. These functions, and the accompanying findings, conclusions, and recommendations, were used to develop a set of criteria to evaluate the adequacy of the portfolio. **The committee recommends that DOE use, at a minimum, the following 10 criteria for this purpose:**

1. **There should be no significant gaps in critical areas of science and technology that are required to address EQ goals and objectives.**
2. **The portfolio should support the accomplishment of closely related DOE and national missions.**
3. **The portfolio should include R&D to develop technical alternatives in cases where: (1) existing techniques are expensive, inefficient, or pose high risks to human health or the environment; or (2) techniques under development have high technical risk.**
4. **The portfolio should produce results that could transform the understanding, need, and ability to address currently intractable problems and which could lead to breakthrough technologies.**
5. **The portfolio should leverage R&D conducted by other DOE business lines, the private sector, state and federal agencies, and other nations to address EQ goals and objectives.**
6. **The portfolio should help narrow and bridge the gap between R&D and application in the field.**
7. **The portfolio should be successful in improving performance, reducing risks to human health and the environment, decreasing cost, and advancing schedules.**
8. **There should be an appropriate balance between addressing long-term and short-term issues.**
9. **A diversity of participants from academia, national laboratories, other federal agencies, and the private sector, including students, postdoctoral associates, and other early-career researchers, should be involved in the R&D.**
10. **There should be an appropriate balance of annual new starts, extensions of promising R&D, and periodic new initiatives.**

PRINCIPAL ELEMENTS OF THE EQ R&D PORTFOLIO

The committee was asked to advise DOE on the principal elements of its EQ R&D portfolio. The committee approached this task in two ways: (1) by developing its own list of elements and (2) by developing a general methodology that DOE could use to build upon this list of program priorities to achieve and maintain a more strategic EQ R&D portfolio. The committee's list of principal elements is presented below (and discussed more fully in Chapter 3), whereas a summary of the proposed methodology is presented in the next section (and discussed more fully in Chapter 4). In developing its list, the committee attempted to take a high-level, long-term view of the R&D needed to address DOE's most challenging EQ problems. Accordingly, the elements generally were not defined along existing DOE program lines and are quite broad.

The committee recommends that DOE's EQ R&D portfolio include, at a minimum, the following 5 principal elements:

1. **Development and evaluation of approaches that reduce the impacts of wastes on human health and the environment through generation minimization; processing improvements, including volume reduction, stabilization, and containment; and disposal.**
2. **Development of methods and techniques for cutting-edge characterization and remediation of contaminated media, including facilities.**
3. **Improvement of understanding of the movement and behavior of contaminants through the environment, with an emphasis on locating and tracking the movement of contaminants in the subsurface.**
4. **Development of mechanisms for effective long-term stewardship, including improved institutional management capabilities, appropriate monitoring, and the means to implement future improvements in technology and understanding.**
5. **Determination of the risks of DOE wastes and contaminated media to human health and the environment to improve the bases upon which regulatory and societal decisions can be made.**

PORTFOLIO MANAGEMENT PROCESS

The committee has described a vision for an EQ R&D portfolio that emphasizes more strongly DOE's long-term EQ problems. To move towards this vision, DOE must redesign and rebalance its EQ R&D portfolio in substantial ways. In Chapter 4 the committee describes a portfolio management process that could help achieve these goals. For the most part DOE can implement the recommended new portfolio management process through an evolutionary approach, i.e., by modifying and supplementing existing management processes. The committee believes this is possible because DOE is already using portfolio management techniques and external reviews have found that management proc esses based on these techniques are yielding positive results but could be greatly improved. Such an approach avoids disruptive reorganizations and maintains management focus on the goal, i.e., realizing the new R&D vision. The key elements of this process are discussed briefly below.

Generating an Improved Set of R&D Project Ideas

DOE's present R&D planning processes for the EQ portfolio are designed primarily to gather current information needs of the sites (i.e., EM cleanup sites or repositories), which tend to be focused primarily on short-term problems and the R&D to address them. Most of the participants in these processes are DOE employees and contractors who are involved in the site problems and issues, with some periodic input from the broader technical community. The existing R&D planning processes are unlikely to generate the full scope of strategic R&D needed to address DOE's most challenging, long-term EQ problems. **The committee recommends that DOE establish a new mechanism within its portfolio management process whose purpose is to develop a more strategic EQ R&D portfolio. This new process, termed the "Strategic Portfolio Review," should supplement and operate in parallel with existing site-driven processes. The Strategic Portfolio Review should be carried out by an independent planning and review board specifically focused on the EQ R&D portfolio, with membership composed of leaders in the scientific and technical community, including experts from industry, academia, national laboratories, and affected communities.** The expanded set of EQ R&D projects to be considered for funding would consist of projects emerging from the traditional needs processes as well as from the new Strategic Portfolio Review.

Measuring the Magnitude of the Benefit

The committee found that DOE does not have a method for prioritizing R&D activities across the entire EQ portfolio. Each DOE organization that supports EQ R&D activities has its own process for prioritizing and selecting R&D activities. The process used to select over 80 percent of the EQ R&D portfolio (those activities supported by EM) is EM's Work Package Ranking System. The current Work Package Ranking System is strongly biased toward activities that are site-generated and connected to the present remediation plans. Moreover, it is, by design, EM specific and therefore does not apply to other parts of the EQ R&D portfolio. The current ranking system is unlikely to be effective in prioritizing R&D ac tivities designed to address the strategic gaps and opportunities identified in the Strategic Portfolio Review discussed above, especially those not within EM. **The committee recommends that DOE develop and implement an evaluation method to address more strategic R&D for the entire EQ R&D portfolio. In the short term, it could be entirely separate from EM's Work Package Ranking System, but, in the longer term, a new approach is needed that works for both site-driven activities and strategy-driven activities and is applied within all areas (i.e., EM, RW, NE) of the EQ R&D portfolio.** Several useful non-EM-specific models that have been applied to elements of the EQ R&D portfolio are discussed in Chapter 4.

R&D Centers

After identifying important strategic R&D activities through the processes described above, it is essential for DOE to provide longer-term support for them, specifically countering the "going out of business within the next decade" philosophy that has permeated some views of the EQ mission. The committee believes that a significant fraction of R&D should be conducted in organizationally separate units to help maintain a focus on long-term results. Each of these units would be strongly coupled to an important, currently intractable EQ problem and evaluated according to progress on solving the problem, but not strongly coupled to short-term program needs. **The committee recommends that DOE implement a new approach to provide longer-term funding for organizationally separate, integrated, and coordinated R&D activities (i.e., R&D centers[9]) designed to solve well-defined, high-priority EQ problems.** Chapter 4 provides details on how DOE could implement this approach.

DETERMINING AN APPROPRIATE LEVEL OF R&D INVESTMENT

EQ is DOE's most expensive business line, accounting for approximately \$6.7 billion, or 36 percent of DOE's total budget. In contrast, the annual investment in EQ R&D is the smallest of DOE's programmatic business lines, accounting for only 4 percent of DOE's total R&D spending. These budget data are an indication that decision makers in DOE, the Office of Management and Budget, and Congress may not fully understand the magnitude and duration of many of the challenges faced by the EQ business line, and the potential value of long-term R&D to ad

[9] The committee refers to the organizations carrying out the integrated and coordinated R&D efforts as "R&D centers" to indicate that the whole of each is greater than the sum of its parts. This synergy could be achieved in more than one way (see discussion in Chapter 4).

dress such challenges.

The appropriate level of R&D funding depends on the scope of the EQ mission and must take into account the balance between spending limited resources on R&D and other possible uses of those resources. Broad-based support for R&D requires a compelling commitment to the goals and objectives of DOE's EQ mission. The committee recommends that DOE develop new strategic goals and objectives for its EQ business line that explicitly incorporate a more comprehensive, long-term view of its EQ responsibilities. After clear goals and objectives have been defined, DOE managers and others will have to deal with difficult tradeoffs in determining the level of R&D funding. There are many important short-term problems that call for high-priority allocation of funds. Often reinforcing or driving these needs are milestones associated with existing compliance agreements between DOE and state environmental regulatory authorities, congressional expectations, and concomitant expectations of the affected communities and their representatives. In such situations, allocating funds to R&D can be seen as taking resources from meeting short-term requirements or compliance agreements to support activities that are, by their very nature, longer term and more uncertain in their ultimate benefits. It is, therefore, incumbent upon DOE leadership to make clear to all EQ stakeholders the value of a strong and sustained R&D portfolio in addressing long-term EQ problems.

It has not been possible to identify an analytic or quantitative approach to establish an appropriate level of EQ R&D funding. There are two general techniques that, together, could be used for this purpose: (1) benchmarking against other mission-driven R&D efforts, both nationally and internationally, and (2) applying a set of investment indicators based closely on the adequacy criteria developed earlier.

Benchmarking the level of EQ R&D funding against similar programs could provide a meaningful measure for discerning a range of reasonable R&D investment levels. It also could help to explain and justify the level of future EQ budget requests to decision makers within DOE, the Office of Management and Budget, and Congress and to other interested parties. **The committee recommends that DOE benchmark the EQ R&D budget against other mission-driven federal R&D programs in the federal government. Such benchmarking exercises should have participation or review by outside experts. Proposed budgets should be presented in the context of benchmarking, and significant deviations from the information gained through benchmarking should be explained.**

The 10 criteria described earlier to evaluate the adequacy of the EQ R&D portfolio also can be used as guides for determining an appropriate level of investment. The committee's list of these 10 investment indicators is provided in Chapter 5. Meeting such criteria is an important indication of an appropriately formulated R&D portfolio. Although the level of

R&D investment alone cannot guarantee the achievement of these indicators, the level of investment should not preclude their achievement. **The committee recommends that DOE use investment indicators, together with benchmarking techniques, to help determine the appropriate level of EQ R&D investments.**

CONCLUSION

DOE's EQ R&D portfolio must be recognized as centrally important to DOE's EQ and other missions, and an enduring responsibility of the department. R&D success requires an adequate, stable, and predictable level of funding. A well-designed, sufficiently funded, and well-implemented EQ R&D portfolio is necessary, but not sufficient, to assure that the potential value of R&D in addressing DOE's EQ problems is achieved. Many other features must be present, including technically competent and trusted R&D program managers; effective relationships among problem holders, R&D managers and researchers; good communication of R&D results; and incentives for R&D results to be used in solving problems.

An effective portfolio also requires close and trusting relationships among the responsible DOE headquarters and local officials, contractors at the sites, state regulatory officials, and stakeholders such as the affected community. The nature of successful EQ R&D is to present opportunities to reduce risks to workers and the public, improve schedules, decrease costs, and solve problems. But it also can require readdressing existing agreements, changing schedules, dealing with periods of uncertainty, and revisiting expectations. All of these factors must be resolved for DOE's EQ R&D to achieve its goals. An EQ R&D portfolio that is well conceived, effectively managed, adequately and consistently funded, and championed by DOE leadership is essential to success in achieving the DOE EQ mission.

1

INTRODUCTION

The U.S. Department of Energy (DOE) is responsible for a diverse range of radioactive, hazardous, and mixed low-level wastes; nuclear materials; spent nuclear fuels; and contaminated lands, waters, and facilities (hereafter referred to collectively as "DOE wastes and contaminated media," [see Sidebar 1.1]). These wastes and contaminated media present the following general scientific, technical, and social challenges that will endure long into the future (see Chapter 2 for a more complete discussion of these challenges):

- Remediate DOE sites[1] and facilities that have severe radioactive and hazardous waste contamination from past activities (also commonly referred to as site "cleanup," see Sidebar 1.2).
- Manage, stabilize, process, and dispose of a legacy of widely varying and often poorly understood DOE wastes (including spent nuclear fuels and nuclear materials treated as waste) that are potential threats to health, safety, and the environment.
- Provide effective long-term stewardship of DOE sites that have been remediated as well as currently practical, but that have residual risks to health, safety, and the environment (see Sidebar 1.2 for definition of "long-term stewardship").
- Develop, open, and operate unique, first-of-a-kind facilities for the permanent disposal of radioactive spent fuels and high-level wastes-many of which will be hazardous for thousands to hundreds of thousands of years.
- Limit contamination and materials management problems, including the generation of wastes and contaminated media, in ongoing and future DOE operations.

[1] See Sidebar 2.2 for a description of the largest DOE sites.

SIDEBAR 1.1 DOE WASTES AND CONTAMINATED MEDIA

Radioactive wastes are the unwanted byproducts of the nuclear fuel cycle and can contain both radioactive isotopes and hazardous chemicals. In the United States, radioactive waste is classified and managed by its source of production rather than by its physical, chemical, or radioactive properties. Consequently, different classes of waste can contain many of the same radioactive isotopes, and even low-level waste can contain certain long-lived radioactive isotopes.

In general, nuclear fuel cycle wastes are grouped into the following broad classes for purposes of management and disposal:

- *High-level waste* is the primary waste produced from chemical processing of spent nuclear fuel. This waste is usually liquid and contains a wide range of radioactive and chemical constituents, and must be solidified before permanent disposal.
- *Spent nuclear fuel* is fuel that has been irradiated in a nuclear reactor, and for the purposes of disposal can include cladding and other structural components.
- *Transuranic waste* excludes high-level waste as defined above and includes waste that contains alpha-emitting transuranium (i.e., atomic number greater than 92) isotopes with half-lives greater than 20 years and concentrations greater than 100 nanocuries per gram. This waste usually consists of contaminated materials like clothing and tools used in the manufacture of nuclear weapons.
- *Mill tailings* are wastes resulting from the processing of ore to extract uranium and thorium.
- *Low-level waste* is radioactive waste that does not meet one of the definitions given above.
- *Mixed low-level waste* is low-level waste that contains both chemically hazardous and radioactive components.

There are two other classes of materials that DOE sometimes manages as waste:

- *Nuclear materials,* such as plutonium and special-use isotopes, that may be declared surplus and disposed of as waste.
- *Contaminated media,* such as contaminated soil, groundwater, and buildings, whose cleanup may generate additional radioactive and chemical waste streams that must be treated and managed.

The term “DOE wastes” is used throughout this report to refer to all wastes and spent nuclear fuels and nuclear materials treated as waste described above for which DOE is responsible. Similarly, the term “DOE wastes and contaminated media” is used to encompass all wastes types, spent nuclear fuels, nuclear materials, and contaminated media described above for which DOE is responsible.

SIDEBAR 1.2 DEFINITIONS OF *CLEANUP* AND *LONG-TERM STEWARDSHIP*

Cleanup

DOE defines *cleanup* as the "process of addressing contaminated land, facilities, and materials in accordance with applicable regulations. Cleanup does not imply that all hazards will be removed from the site" (DOE, 1999a).

According to DOE, site cleanup is complete when the following five criteria have been met:

1. Deactivation or decommissioning of all facilities currently in the EM program have been completed, excluding any long-term surveillance and monitoring.
2. All releases to the environment have been cleaned up in accordance with agreed-upon cleanup standards.
3. Groundwater contamination has been contained and long-term treatment (remedy) or monitoring is in place.
4. Nuclear materials have been stabilized and/or placed in safe long-term storage.
5. Legacy waste has been disposed of in an approved manner (legacy waste was produced by past nuclear weapons production activities. (DOE, 1998).

As DOE has stated, "completing cleanup," also commonly referred to as site "closure," does not mean that the site will be made available for unrestricted use. In fact most DOE sites will require some form of long-term stewardship (see below) to protect human health and the environment from hazards after cleanup is complete.

Long-Term Stewardship

DOE defines long-term stewardship as "all activities necessary to ensure protection of human health and the environment following completion of cleanup, disposal, or stabilization at a site or a portion of a site. Long-term stewardship includes all engineered and institutional controls designed to contain or to prevent exposures to residual contamination and waste, such as surveillance activities, record-keeping activities, inspections, groundwater monitoring, ongoing pump and treat activities, cap repair, maintenance of entombed buildings or facilities, maintenance of other barriers and containment structures, access control, and posting signs" (DOE, 2001c).

DOE currently spends approximately $6.7 billion a year on activities designed to address these challenges. DOE refers to these activities as its Environmental Quality (EQ) "business line."

The magnitude and duration of these challenges are related to:

- the quantities of DOE wastes and contaminated media that are distributed at numerous sites throughout the United States;
- the quantities of wastes and contaminated media currently outside DOE (or to be generated in the future) that are expected to be added to DOE's current inventories;
- the long half-lives (thousands to hundreds of thousands of years) of some of the radioactive elements contained in these materials; and
- the potential risks to humans and the environment if radioactive materials (and related hazardous substances) are not adequately isolated from the biosphere.

The long-term nature of these challenges and the enormous costs associated with them create many opportunities to improve methods, lower costs, reduce impacts to human health and the environment, and improve stewardship through a strengthened long-term research and development (R&D) effort (see Sidebar 1.3 for definitions of "research" and "development"), as discussed in more detail in Chapter 3. One direct effect could be to reduce the costs of managing and disposing of DOE wastes and contaminated media through the development of more cost-effective approaches. Long-term R&D also could lead to novel approaches to reduce the risks of DOE wastes and contaminated media to human health and the environment to levels that are not possible given current technical capabilities and understanding. Another significant potential impact of long-term EQ R&D is improvement in technical understanding of issues related

SIDEBAR 1.3 DEFINITIONS OF "RESEARCH" AND "DEVELOPMENT"

The committee has adopted the definitions of "research" and "development" that are used by the National Science Foundation, the Office of Management and Budget, and federal agencies (including DOE) to report R&D funding data. The term "research" is defined as systematic study directed toward more complete scientific knowledge or understanding of the subject studied. The term "development" is defined as the systematic use of the knowledge or understanding gained from research for the production of materials, devices, systems, or methods, including design, development, and improvement of prototypes and new processes. It excludes quality control, routine product testing, and production. Therefore, throughout this report the short-hand "R&D" is used to include all stages of technology maturation from research through demonstration and initial deployment of a new technology, rather than the more precise term "research, development, demonstration, and deployment", or "RDD&D."

Source of Definitions: American Association for the Advancement of Science, http://www.aaas.org/spp/dspp/re/define.htm.

to cleanup, long-term stewardship, and the disposal of radioactive wastes, which could help policy makers make more informed decisions.

R&D activities designed to address these challenges are supported principally by three offices: the Office of Environmental Management (EM), the Office of Civilian Radioactive Waste Management (RW), and the Office of Nuclear Energy, Science and Technology. In addition, the Office of Fissile Materials Disposition conducts a small amount of R&D as part of the EQ business line, and DOE's Office of Science, which is not formally part of the EQ business line, supports a variety of basic research activities related to DOE's EQ mission. A brief overview of the types of R&D supported by these offices is provided in Sidebar 1.4.

DOE'S R&D PORTFOLIO PROCESS

In 1998 DOE began an effort under the direction of the Under Secretary to develop comprehensive descriptions of its R&D activities. These descriptions have been organized into R&D portfolio documents that describe the collection of R&D activities (i.e., the R&D portfolio[2]) which supports each of the four programmatic business lines[3] established in DOE's strategic plan (DOE, 1997b, 2000f): EQ (DOE, 2000b), Energy Resources (DOE, 2000a), National Nuclear Security (DOE, 2000c), and Science (DOE, 2000d). The primary objective of this portfolio-development effort was to ensure that R&D activities are focused on the goals outlined in DOE's strategic plan. DOE stated that it would use these portfolios to better manage its R&D programs, most notably in the following ways:

- to increase coordination and integration of R&D activities across the department;
- to identify R&D gaps and opportunities;
- to balance R&D investments; and
- to provide a coherent rationale for R&D budget requests to the Office of Management and Budget and the U.S. Congress.

Although DOE's motivation for the portfolio reviews did not include a need to examine DOE's R&D responsibilities in the context of other U.S. and international agencies, the committee believes that this is an important issue to consider as well. The role of the EQ R&D portfolio in ad

[2] The committee uses the term "portfolio" to refer to the collection of R&D activities that support each of DOE's four programmatic business lines, and the term "portfolio document" to refer to the published description of these activities.

[3] The four programmatic business lines are supported by a corporate management function, which DOE's most recent strategic plan refers to as a fifth business line (DOE, 2000f).

dressing non-DOE problems, both national and international, is an explicit charge to this committee (see below).

STATEMENT OF TASK

The Under Secretary of Energy asked the National Academies' National Research Council to address the following questions related to the EQ R&D portfolio, with a focus on post-2006 research:

- In the context of EQ strategic goals and mission objectives, what criteria should be used to evaluate the adequacy of the portfolio?
- Using these criteria, what should be the principal elements of the portfolio?
- Should the portfolio be designed to address environmental problems outside DOE (e.g., Department of Defense, Russia) that are related to EQ strategic goals?
- How to determine the level of future investments in EQ R&D?

One issue that the committee had to address in carrying out the study was how to interpret the phrase "with a focus on post-2006 research." In 1996 EM established a formal goal of completing cleanup at as many sites as possible by the year 2006 (DOE, 1998). Because this goal focuses exclusively on the number of sites "cleaned up" by 2006 (see Sidebar 1.2), it has had a major effect on EM's approach to remediation activities. In particular, the goal created an incentive to focus resources on sites that could realistically be cleaned up within a 10-year or shorter time frame relative to larger sites faced with more difficult problems. It also may have given the incorrect perception to some federal decision makers that environmental problems associated with DOE wastes and contaminated media would largely be addressed by 2006 (see discussion in Chapter 2). The short-term focus of the goal has had a marked impact on the types of R&D activities supported by EM: It created a clear incentive to support late-stage development and deployment of techniques that could be used in the near term to facilitate cleanup of sites by 2006, and a disincentive to fund long-term R&D activities that might address the more difficult problems that will endure beyond 2006. These factors, together with other external forces driving EM to produce results quickly (i.e., congressional expectations, regulatory constraints), have resulted in a portfolio of EM R&D activities heavily weighted toward short-term needs. It also may partly account for the recent trend of decreasing investments in EQ R&D (see discussion in Chapter 5).

Although the year 2006 has no special meaning for the other DOE organizational units involved in the EQ business line, RW also has been driven to focus its R&D activities on short-term needs—most notably, sci

SIDEBAR 1.4 DEPARTMENT OF ENERGY OFFICES THAT SUPPORT EQ R&D

Five DOE offices support R&D related to DOE's EQ business line. The missions of these offices, their significant EQ R&D efforts, and their total EQ R&D funding levels are summarized briefly below.

Office of Environmental Management (EM)

In 1989, Congress established EM to reduce threats to health and safety posed by environmental contamination at DOE sites. Most of the R&D activities considered part of the EQ R&D portfolio are supported by EM's Office of Science and Technology (OST) and by the Environmental Management Science Program (EMSP), which is administered jointly by EM and the Office of Science. Activities conducted by the sites themselves to develop new techniques or refine existing techniques are not considered part of DOE's EQ R&D portfolio because they are integral parts of large operating projects (see Sidebar 2.2 for more information on DOE sites).

OST's mission is to manage and direct a national, solution-oriented science and technology program to provide the scientific foundation, new approaches, and new technologies that could significantly reduce the risk, cost, and time needed for completion of the EM cleanup mission. To accomplish this mission, OST supports technology-development activities in five focus areas (deactivation and decommissioning, nuclear materials, subsurface contamination, tanks, and transuranic and mixed low-level waste) and in five crosscutting areas (characterization, monitoring, and sensor technology; efficient separations; industry/university programs; long-term stewardship; and robotics). EMSP supports mission-driven basic research of relevance to EM's cleanup mission. EM's EQ R&D budget in fiscal year (FY) 2001 is approximately $240 million.

Office of Civilian Radioactive Waste Management (RW)

The Nuclear Waste Control Act of 1982 established RW to develop and manage a federal system for disposing of all spent nuclear fuel from commercial nuclear reactors and high-level radioactive waste and spent nuclear fuel resulting from atomic energy defense activities. The Nuclear Waste Policy Amendments Act of 1987 directed DOE to characterize only Yucca Mountain, Nevada, to determine its suitability as a repository site for the disposal of spent nuclear fuel and high-level radioactive waste. RW's R&D activities address the following issues: understanding the effects of heat on repository system performance, building a three-dimensional model of the Yucca Mountain site, enhancing repository design, improving the design of waste packages and drip shields, developing dry transfer systems for spent nuclear fuel, conducting performance assessments for various repository conditions, and improving the understanding of the saturated zone beneath Yucca Mountain. RW's EQ R&D budget in FY 2001 is approximately $45 million.

Office of Nuclear Energy, Science, and Technology (NE)

NE is responsible for managing the federal government's investment in nuclear science and technology and supporting innovative applications of nuclear technology. Most of NE's R&D activities considered part of the EQ R&D portfolio address the management of existing inventories of depleted uranium hexafluoride[a] and sodium-bonded spent nuclear fuel. NE sponsors investigator-initiated, peer-reviewed research at universities, national laboratories, and industry through its Nuclear Energy Research Initiative (NERI). One component of NERI is to support research on advanced spent fuel treatment technologies (such as electrometallurgical treatment technologies) that could reduce the volume of spent nuclear fuel and other radioactive waste. At the direction of Congress, NE also is examining the feasibility of accelerator transmutation of waste technologies, which offer the potential to reduce the amount of long-lived radionuclides in waste by transforming plutonium, long-lived actinides, and long-lived fission products contained in spent fuel. NE's EQ R&D budget in FY 2001 is approximately $11 million.

Office of Fissile Materials Disposition (MD)

MD is responsible for all activities of DOE's National Nuclear Security Administration relating to the management, storage, and disposition of fissile materials from weapons and weapon systems that are excess to U.S. security needs. MD EQ R&D focuses on developing techniques to transform weapons-usable plutonium to forms that are not readily accessible for use in nuclear weapons. MD's EQ R&D budget in FY 2001 is approximately $3 million.

Office of Science (SC)

SC funds basic research organized around four main themes: (1) fueling the future (including research on new fuels, and clean and affordable power), (2) protecting our living planet (including energy impacts on people and the environment); (3) exploring matter and energy, and (4) extraordinary tools for extraordinary science (including national assets for multidisciplinary research). Although SC is not formally part of DOE's EQ R&D portfolio, it supports a variety of research activities related to DOE's EQ mission, primarily within its Office of Basic Energy Sciences (BES) and the Office of Biological and Environmental Research (BER). BES research efforts that could have an impact on DOE's EQ mission include some elements of the geoscience, separations science, and materials science and engineering programs. BER research efforts that could have an impact on DOE's EQ mission include some elements of its natural and accelerated bioremediation program and its Environmental Molecular Sciences Laboratory.

[a] In October 2000 the depleted uranium cleanup program was transferred from NE to EM.

entiflc investigations to assess the suitability of the proposed Yucca Mountain repository, which if approved and licensed, could begin receiving waste as early as 2010—even though the program will endure and should benefit from R&D for generations if successful. Therefore, by asking the committee to focus on post-2006 R&D activities, DOE was looking for advice on how the EQ R&D portfolio could shift its current short-term focus to a more long-term, strategic view. Throughout this report the committee uses the term “short-term” to mean 5 years or less, and “long-term” to mean greater than 5 years.

Finally, part of the committee’s task is to provide “criteria…to evaluate the adequacy of the portfolio” and to “identify the principal elements of the portfolio.” To this end Chapter 3 describes a long-term vision for the EQ portfolio, and Chapter 4 describes how DOE could achieve the vision. One might say that, in the narrowest sense of the term “criteria,” Chapter 3 fulfills the task and Chapter 4 exceeds it. However, the committee believes that it is important to describe more than where the portfolio should be when it is “adequate,” for doing only that would provide little practical guidance today on steps to move in the correct direction. Describing the characteristics of an adequate portfolio is necessary but not sufficient. It is also necessary to describe a process that will achieve and maintain an adequate portfolio. This is the proverbial difference between giving a man a fish and teaching him to fish. In sum, one criterion for an adequate portfolio is a process to develop and maintain it.

STUDY PROCESS

The National Academies appointed a committee of twelve experts[4] with a range of perspectives and experience related to the task (see Appendix A for biographical information on committee members). The committee held its first information-gathering meeting on June 7 and 8, 2000, in Washington, D.C. During this meeting, it discussed its task with DOE leadership and heard presentations from a number of DOE program managers. The primary information-gathering activity for the study was a two-day public workshop held in Washington, D.C. on August 23 and 24, 2000. This workshop brought together approximately 50 participants from DOE, the private sector, academia, and other federal agencies (see Appendix B for a list of participants and the workshop agenda). The workshop began with a series of keynote speakers who discussed various aspects of DOE’s EQ R&D activities. Participants were then organized into three working groups to examine issues associated with: (1) identifying

[4] Teresa Fryberger, who served as vice-chair of the committee, recused herself from committee activities in November 2000 and resigned from the committee in January 2001 after accepting a management position within DOE-EM.

significant long-term EQ R&D needs; (2) evaluating the balance and value of the EQ R&D portfolio; and (3) determining the appropriate level of investment in long-term EQ R&D. Prior to the workshop, the committee also solicited input on significant long-term R&D needs from persons knowledgeable about DOE's EQ mission, and these issues were used as input to the workshop. The committee then held two closed meetings during which it developed its findings, conclusions, and recommendations and prepared this report.

This study complements and builds on two other recent analyses of DOE's EQ R&D portfolio. Last year DOE's Strategic Laboratory Council[5] conducted an adequacy analysis to examine the capability of the current portfolio of DOE R&D activities to meet the objectives of the EQ business line (DOE, 2000g). Based on an extensive review of the current portfolio, the adequacy analysis recommended a number of changes to DOE's EQ strategic goal and objectives, identified a large number of R&D gaps and opportunities,[6] and offered findings and recommendations on how the portfolio could be improved. After the adequacy analysis was published, the Technology Development and Transfer Committee of DOE's Environmental Management Advisory Board (EMAB)[7] was asked to evaluate the analysis, resulting in an EMAB letter report in October 2000 (DOE, 2000g). The results of the adequacy analysis and the EMAB letter report are summarized in Appendix C.

ORGANIZATION OF REPORT

This chapter has provided an introduction and general background on the issues addressed in the report. Chapter 2 describes the mission of DOE's EQ business line, summarizes its major areas of responsibility, and

[5] The Strategic Laboratory Council (SLC) consists of representatives from DOE's national laboratories. It provides assistance to EM offices and EM-related science organizations on science and technology issues dealing with EM's program. Operating in a consensus manner, the SLC develops positions and offers recommendations that represent the DOE laboratory system. SLC members took the lead in organizing panels to conduct the adequacy analysis of the EQ R&D portfolio.

[6] According to the SLC's adequacy analysis, an R&D gap exists where "the current portfolio is less than adequate in some respect (e.g., lacking needed work), thus posing a risk of failure to achieve an EQ objective." An R&D opportunity exists "when there is significant potential to achieve a high return on investment or to excel in achieving an EQ objective through a new research area or more investment in an existing research area" (DOE, 2000g).

[7] EMAB is an advisory group chartered to provide advice to DOE's Assistant Secretary for EM on issues related to environmental restoration and waste management issues. EMAB members are chosen to represent key stakeholder groups in EM's decision-making process. EMAB carries out much of its work through its committees, including the Technology Development and Transfer Committee (which focuses on technology-related issues) and the Science Committee (which focuses on the quality of science in the EM program). Also see Sidebar4.1.

discusses issues associated with the scope of the EQ mission. Chapters 3 and 4 together provide the committee's vision for a more effective long-term EQ R&D portfolio. Chapter 3 begins by discussing the important functions of such a portfolio, which are used as the basis of the committee's list of criteria to evaluate the adequacy of the portfolio that follows. Based on these criteria and the findings of many recent studies, the committee develops a short list of principal elements, presented at the end of Chapter 3, that it believes are going to be essential to the success of DOE's long-term EQ mission. Chapter 4 then describes how DOE could build upon the adequacy criteria and principal elements developed in Chapter 3 to achieve and maintain a more strategic, long-term R&D portfolio. Finally, Chapter 5 describes processes that could be used to help determine an appropriate level of investment in EQ R&D. Supporting materials are included as Appendixes A through F.

2

THE DEPARTMENT OF ENERGY'S ENVIRONMENTAL QUALITY MISSION

The Department of Energy's (DOE's) Environmental Quality (EQ) business line encompasses some of the largest, costliest, and most complex environmental remediation, nuclear and hazardous materials management, and waste disposal programs in the world (OTA, 1991, 1993a,b; DOE, 1995). In this chapter the committee focuses on the mission of the business line, rather than its research and development (R&D) activities. The purpose of the chapter is to provide the context that is required for the analyses of the R&D portfolio in the rest of the report. To do so, the committee provides a high-level overview of the major areas of responsibility of the business line and important elements of its budget. The committee also discusses and clarifies its views on the topical and temporal breadth of DOE's EQ mission.

DOE'S EQ RESPONSIBILITIES

A general sense of the magnitude and enduring nature of DOE's EQ responsibilities can be ascertained from the quantities of DOE wastes and contaminated media[1] involved, the estimated life-cycle costs[2] for protecting human health and the environment from these wastes and contaminated media, and estimates of how long it will take to address these issues using existing technologies and current technical understanding. Table 2.1 summarizes these data, as well as annual R&D budgets, for each of the ten technical categories of the EQ business line. (More detailed descriptions of these technical categories are provided in Appendix D.) Some of the most significant characteristics of DOE's envir

[1] See Sidebar 1.1 for definition of "DOE wastes and contaminated media."

[2] All life-cycle cost data in this chapter are DOE's estimates of the costs of addressing these problems at all DOE sites from fiscal year 1997 through 2070 in 1999 dollars (DOE, 2000e). This total incudes some costs already incurred in fiscal years 1997 through 2000. The committee has not validated the accuracy of these estimates.

TABLE 2.1 Summary of Major Technical Categories Addressed by DOE's EQ R&D Portfolio

Technical Category[a]	Quantities	Major Sites	Life-Cycle Costs[b]	Estimated Duration of Problem	Annual R&D Budget (FY 2001 request)[b]	Responsible DOE Office[f]
Manage high-level waste	340,000 m^3 stored in 280 large tanks and 63 smaller tanks	Savannah River, Hanford, INEEL, Oak Ridge, West Valley	$53.5 billion	Decades	$62 million	EM
Manage mixed low-level waste (MLLW) and transuranic (TRU) waste	165,000m^3 at 36 sites; an additional 45,000 m^3 of TRU and 170,000 m^3 of MLLW will be generated in next 10 years	36 sites	More than $18 billion	Decades	$37.8 million	EM
Manage spent nuclear fuel	2,100 MTHM[c]—Hanford 330 MTHM—INEEL 50 MTHM—Savannah River 85,000 MTHM commercial spent fuel	Hanford, INEEL, Savannah River	$7.8 billion	Decades	$36.3 million	EM, NE
Manage nuclear material	200 metric tons of weapons-usable fissile materials; >700,000 metric tons of uranium hexafluoride	Rocky Flats Others	$6.4 billion	Decades	$24.4 million	EM, NE, MD

Dispose high-level waste, spent nuclear fuel, and nuclear materials	85,000 MTHM of commercial spent fuel; 22,000 canisters of high-level waste; 2,500 MTHM of DOE spent fuel	Yucca Mountain	$52–57 billion	Decades	$44.6 million	RW
Dispose TRU, low-level, mixed low-level, and hazardous wastes	165,000 m^3 of mixed low-level and TRU waste at 36 sites; an additional 45,000 m^3 of TRU and 170,000 m^3 of MLLW will be generated in next 10 years	WIPP (TRU); Hanford, Savannah River, INEEL, Envirocare (low-level waste)	$8.1 billion for WIPP	Estimated closure date for WIPP is 2039	No separate R&D budget	EM
Environmental remediation	3 million m^3 of buried, solid radioactive and hazardous waste; 75 million m^3 of contaminated soil; 1.8 billion m^3 of contaminated groundwater	INEEL, Oak Ridge, Hanford, Rocky Flats, Savannah River	$12.6 billion	Cleanup estimated to continue through 2070	$58.8 million	EM
Deactivation and decommissioning	2,700 buildings containing over 180,000 MTHM	All	More than $37 billion	Cleanup estimated to continue through 2070	$21.7 million	EM

Technical Category[a]	Quantities	Major Sites	Life-Cycle Costs[b]	Estimated Duration of Problem	Annual R&D Budget (FY 2001 request)[b]	Responsible DOE Office[f]
Long-term stewardship	129 DOE sites will require some form of long-term stewardship	129 sites	Currently spends $64 million/year. By 2050, costs are estimated to be nearly $100 million/year[d]	Indefinite, potentially thousands of years	No separate R&D budget	EM
Minimize waste Generation	Not applicable	All	Estimates not available	Continuing	No separate R&D budget	All

[a] Technical categories are those from the Strategic Laboratory Council's Adequacy Analysis (DOE, 2000g). See Appendix D for descriptions of technical categories.

[b] Data from Strategic Laboratory Council's Adequacy Analysis (DOE, 2000g).

[c] metric tons heavy metal.

[d] Estimates from DOE (2001 b).

[e] Waste Isolation Pilot Plant.

[f] Office of Environmental Management (EM), Office of Civilian Radioactive Waste Management (RW), Office of Nuclear Energy, Science and Technology (NE); Office of Fissile Materials Disposition (MD).

onmental cleanup, materials management, and waste disposal responsibilities are discussed below.

Addressing Environmental Contamination at DOE Sites

The DOE Office of Environmental Management (EM) is responsible for addressing environmental contamination problems at 140 sites located in 31 states (DOE, 1998; 1999a), which are referred to collectively as "the DOE complex" (see Sidebar 2.1). To date, DOE has identified almost 10,000 individual locations at these sites where toxic or radioactive substances were improperly abandoned or released directly into soil, groundwater, or surface waters (DOE, 1997a). An estimated 75 million cubic meters (2.6 billion cubic feet) of contaminated soil and 1.8 billion cubic meters (475 billion gallons) of contaminated groundwater may need to be remediated at these sites (DOE, 1997a). EM also is responsible for the deactivation and decommissioning of 2,700 facilities (of a total of about 20,000) determined to be surplus in the DOE complex (DOE, 1997a). Most of these facilities are seriously contaminated with radioactive or hazardous substances at levels that prohibit unrestricted release. Environmental remediation and deactivation and decommissioning activities are expected to continue at some sites through 2070, at a total life-cycle cost of nearly $50 billion for the entire DOE complex (DOE, 2000g).

Managing DOE Wastes, Spent Nuclear Fuels, and Nuclear Materials

EM is responsible for more than 36 million cubic meters (9.6 billion gallons) of hazardous or radioactive wastes (DOE, 1997a), including over 340,000 cubic meters (90 million gallons) of high-level radioactive waste. Managing these wastes is extremely challenging, because of the volumes at issue, their hazardous characteristics, their long periods of toxicity and because much of it (including some of the most dangerous) is in unstable configurations (e.g., the Hanford tanks), much has been released to the environment already, and much of the waste is at present very incompletely characterized.

EM and DOE's Office of Nuclear Energy, Science and Technology (NE) also are responsible for managing over 800 million kilograms (1.8 billion pounds) of non-waste materials in inventory, such as depleted uranium, plutonium spent nuclear fuel, lead, sodium, lithium, and a variety of chemicals (DOE, 1996). Most of these materials, the majority of which is depleted uranium, are stored at 44 facilities at 11 major production sites throughout the United States. DOE's radioactive waste (including spent nuclear fuel and nuclear materials treated as waste) man

SIDEBAR 2.1 THE DOE COMPLEX

Although the DOE complex encompasses over 100 distinct sites, the largest volumes of DOE wastes and contaminated media and many of the most costly and most challenging EQ problems are found at the six largest sites described below. The estimated site closure date and life-cycle costs for each site are those from EM's recent report, *Status Report on Paths to Closure* (DOE, 2000e).

1. The **Hanford Site** is in southeastern Washington State and covers an area of about 1,450 square kilometers (560 square miles). Production of materials for nuclear weapons took place here from the 1940s until mid-1989. The site contains several shutdown production reactors, chemical separations plants, and solid and liquid waste storage sites. **Estimated closure date: 2046. Estimated life-cycle costs: $56 billion.**
2. The **Savannah River Site,** near Aiken, South Carolina, covers an area of about 800 square kilometers (300 square miles). The site was established in 1950 to produce special radioactive isotopes (e.g., plutonium-239 and tritium) for use in the production of nuclear weapons. The site contains shutdown production reactors, chemical processing plants, and solid and liquid waste storage sites. **Estimated closure date: 2038. Estimated life-cycle costs: $37 billion.**
3. The **Idaho National Engineering and Environmental Laboratory,** first established as the Nuclear Reactor Testing Station and then the Idaho National Engineering Laboratory, occupies 2,300 square kilometers (890 square miles) in a remote desert area along the western edge of the upper Snake River plain. The site was established as a building, testing, and operating station for various types of nuclear reactors and propulsion systems, and the site also manages spent fuel from the naval reactor program. **Estimated closure date: 2050. Estimated life-cycle costs: $21 billion.**
4. The **Rocky Flats Environmental Technology Site** occupies about 140 hectares (~350 acres) near Denver, Colorado, and has more than 400 manufacturing, chemical processing, laboratory, and support facilities that were used to produce nuclear weapons components. Production activities once included metal working, fabrication and component assembly, and plutonium recovery and purification. Operations at the site ceased in 1989. **Estimated closure date: 2006. Estimated life-cycle costs: $8 billion.**
5. The **Oak Ridge Reservation** covers an area of approximately 155 square kilometers (60 square miles) west of Knoxville, Tennessee. The reservation has three major operating facilities: the Oak Ridge National Laboratory, the Y-12 Plant, and the K-25 Plant. **Estimated closure date: 2014. Estimated life-cycle costs: $6.5 billion.**
6. The **Nevada Test Site,** which occupies about 3,500 square kilometers (1,350 square miles) in southern Nevada, was the primary location for atmospheric and underground testing of the nation's nuclear weapons starting in 1951. **Estimated closure date: 2014. Estimated life-cycle costs: $2 billion.**

agement responsibilities are expected to continue for many decades at an estimated total life-cycle cost of more than $85 billion (DOE, 2000g).

Disposing of DOE Wastes, Spent Nuclear Fuels, and Nuclear Materials

DOE's Office of Civilian Radioactive Waste Management (RW) is responsible for developing and managing a system to permanently dispose of a currently estimated 85,000 metric tons of heavy metal (MTHM) of commercial spent fuel, 2,500 MTHM of DOE spent fuel, and 22,000 canisters of high-level waste. RW currently is investigating the suitability of the Yucca Mountain Site as a geological repository for such wastes (see Sidebar 2.2). The total cost of disposing of high-level waste, spent nuclear fuel, and nuclear materials in Yucca Mountain is estimated to be $52 to $57 billion over at least the next three to four decades (DOE, 2000g).

EM is responsible for disposing of approximately 167,000 cubic meters (5.9 million cubic feet) of transuranic waste in the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico (see Sidebar 2.3). The estimated life-cycle costs of WIPP through its estimated closure date of 2039 is $8 billion (DOE, 2000g).

DOE low-level waste is disposed of in shallow land facilities at several locations. Low-level waste from defense programs is disposed of generally at the site where it was produced, primarily Hanford, the Savannah River Site, and the Idaho National Engineering and Environmental Laboratory. Envirocare in Utah receives very low level waste, for example, from facility decommissioning.

DOE's EQ Challenges

The preceding discussion makes clear that the EQ business line is responsible for managing and controlling a large number of facilities and huge volumes of DOE wastes and contaminated media under a broad range of conditions. For brevity, the committee has developed the following summary statement of the scientific and technical challenges that face the EQ business line, hereafter referred to as DOE's "EQ challenges":

- Remediate (i.e., "clean up") DOE sites and facilities that have severe radioactive and hazardous waste contamination from past activities. In many cases the extent, location, or types of contamination are not well known, and methods to clean them up safely, timely, effectively, and economically are not available. Indeed, in many cases, DOE is unable to defensibly determine whether cleanup is required and its relative priority.

SIDEBAR 2.2 YUCCA MOUNTAIN: A CANDIDATE SITE FOR A GEOLOGICAL REPOSITORY FOR HIGH-LEVEL WASTE AND SPENT NUCLEAR FUEL

- Current U.S. plans call for commercial spent nuclear fuel, high-level waste and spent nuclear fuel at DOE sites, and some nuclear materials (e.g., excess weapons-grade plutonium) to be disposed of in a geological repository. One site, located in Yucca Mountain, Nevada, is being characterized to determine its suitability to serve as a repository.

The 1982 Nuclear Waste Policy Act established a process for siting, developing, licensing, and constructing a geological repository and established an Office of Civilian Radioactive Waste Management within DOE to manage this process. The act also placed primary responsibility for spent nuclear fuel storage on its producers—DOE defense sites and commercial nuclear power plants. DOE initially identified several potential repository sites, including Yucca Mountain; Deaf Smith County, Texas; and Hanford, Washington. The 1987 Nuclear Waste Policy Amendments Act limited site characterization to the Yucca Mountain Site.

DOE completed a viability assessment of its Yucca Mountain Site in 1998. According to the current schedule for the Yucca Mountain Characterization Program, DOE plans to submit a site recommendation to the President in 2001. The President may then submit a site recommendation to Congress, at which point the Governor or the state legislature of Nevada has the right to file a notice of disapproval, which could be overridden by majority votes in both Houses of Congress. If the site is found to be viable and Congress appropriates the necessary funds, DOE plans to submit a license application to the Nuclear Regulatory Commission in 2002. If approved and licensed, Yucca Mountain could begin receiving waste as early as 2010. Current plans call for the repository to remain open for at least 50 years and possibly as long as 300 years before a decision is made to decommission and close the facility. During this preclosure period, performance confirmation and monitoring activities would continue.

- Manage, stabilize, process, and dispose of a legacy of widely varying and often poorly understood DOE wastes (including spent nuclear fuels and nuclear materials treated as waste) that are potential threats to health, safety, and the environment. The techniques required to characterize, process, and treat these wastes are often undeveloped or poorly realized.
- Provide effective long-term stewardship of DOE sites that have been remediated as well as currently practical but that have residual

risks to health, safety, and the environment.

SIDEBAR 2.3 THE WASTE ISOLATION PILOT PLANT

- The Waste Isolation Pilot Plant (WIPP) is the world's first specially constructed deep geologic repository for long-lived radioactive waste. WIPP has sufficient planned capacity to accommodate the entire inventory of U.S. defense transuranic waste (primarily contaminated clothing, tools, equipment, and debris resulting from the manufacture of nuclear weapons and cleanup of weapons production sites). WIPP is located in the semiarid desert of southeastern New Mexico. The repository itself consists of mined shafts, tunnels, and waste disposal rooms in 250-million-year-old bedded salt about 650 meters beneath the land surface.

  WIPP opened in 1999 and is currently receiving a few shipments of waste per week from several weapons production sites. The waste is being shipped to WIPP in boxes and 55-gallon drums for direct emplacement in the repository. Once the repository is filled with waste, the access tunnels and shafts will be backfilled to the surface and permanently sealed. The repository is expected to remain open until about 2039.

- Develop, open, and operate unique, first-of-a-kind facilities for permanent disposal of radioactive spent fuels and high-level wastes, many of which will be hazardous for thousands to hundreds of thousands of years.
- Limit contamination and materials management problems, including the generation of wastes and contaminated media, in ongoing and future DOE operations.

These EQ challenges drive the EQ R&D portfolio.

EQ BUDGET AND R&D FUNDING

EQ is DOE's second most expensive business line, accounting for $6.7 billion (or 34 percent) of the $19.7 billion DOE budget for fiscal year 2001 (see Figure 2.1 a). In contrast, the annual investment in EQ R&D is the smallest of DOE's four programmatic business lines. For fiscal year 2001, funding for EQ R&D was approximately $298 million (or 4 percent) of DOE's total R&D spending (see Figure 2.1b). These budget data suggest that decision makers in DOE, the Office of Management and Budget, and Congress have not viewed R&D as an effective way to meet DOE's EQ responsibilities. One reason for this view may be the incorrect perception that DOE's EQ problems[3] largely will be addressed in the next

[3] The term "EQ problems" refers to the set of technical problems that collectively make up the "EQ challenges" described in the text. This is a useful concept in planning an R&D

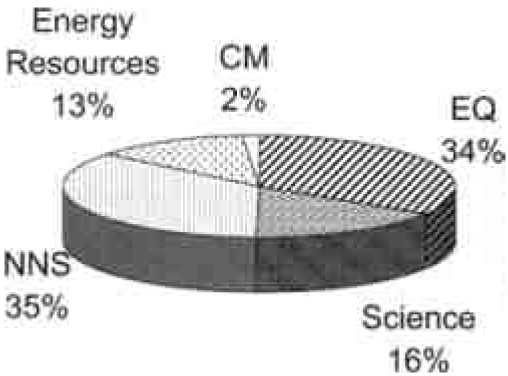

FIGURE 2.1 (a) DOE Fiscal Year 2001 Budget by Business Line. Of DOE's total budget of approximately $19.7 billion, $7.0 billion (35%) is spent by National Nuclear Security (NNS), $6.7 billion (34%) by Environmental Quality (EQ), $3.2 billion (16%) by Science, $2.5 billion (13%) by Energy Resources, and 0.3 billion (2%) by Corporate Management and Other (CM). Approximately 41% of DOE's $19.7 billion budget ($8.0 billion) is spent on R&D, which is distributed among the business lines as shown in (b). Data from Department of Energy Office of Chief Financial Officer. Available at:
(http://www.cfo.doe.gov/budget/02budget/3-pager.pdf)

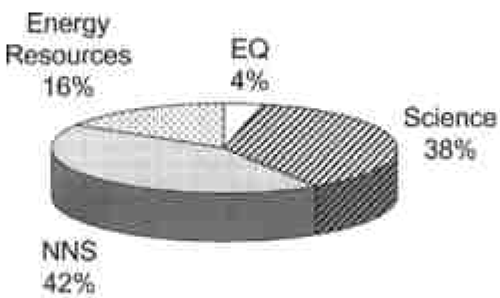

FIGURE 2.1 (b) DOE Fiscal Year 2001 R&D Spending by Business Line. Of DOE's $8.0 billion R&D investment, $3.4 billion (42%) is spent by NNS, $3.0 billion (38%) by Science line, 1.3 billion (16%) by Energy Resources, and $298 million (4%) by EQ. Data for NNS, Science, and Energy Resources are from AAAS (2001); data for EQ are from Ker-Chi Chang, DOE (personal communication).

portfolio because the challenges are very broad, and must be broken down into manage-able parts to be addressed by R&D.

few years (this issue is discussed below in "Temporal Breadth of DOE's EQ Mission"). The committee examines EQ R&D budget issues more fully in Chapter 5.

SCOPE OF DOE'S EQ MISSION

The scope of DOE's EQ mission was the subject of extensive deliberation and discussion within the committee. It is important consider this issue early in the report because any consideration of the adequacy of an R&D portfolio requires a clear understanding of the programmatic objectives that these R&D activities are intended to support—in this case, DOE's EQ mission. Such clarity is a challenge because DOE's use of the term "environmental quality" is a misnomer that creates confusion, both within and outside DOE, and because DOE documents reviewed by the committee are not consistent in describing the EQ mission.[4] For example, the EQ strategic goal and objectives in DOE's 1997 Strategic Plan (DOE, 1997b), which was in effect when the EQ R&D portfolio document was compiled, differ substantively in several ways from those in DOE's 2000 Strategic Plan (see Sidebar 2.4). In particular, the 1997 Strategic Plan explicitly recognizes the importance of limiting the generation of future DOE wastes by including "minimize future waste generation" as part of the strategic goal and "prevent future pollution" as one of seven objectives. In addition, the 1997 Plan emphasizes the importance of focusing on the most serious risks (objective 1) and reducing the costs of environmental cleanup (objective 6). None of these important concepts were included in the strategic goal and objectives of DOE's 2000 strategic plan. In spite of these substantive differences, however, the strategic goal and objectives in both strategic plans (see Sidebar 2.4) clearly focus on addressing problems related to DOE wastes and contaminated media.

However, other parts of the 1997 strategic plan and the EQ R&D portfolio document (DOE, 2000b) suggest that the scope of DOE's EQ mission may extend beyond DOE wastes and contaminated media. For example, the 1997 strategic plan states that one of the three primary areas of responsibility of the EQ business line is to "provide the technolo

[4] The committee believes that the most appropriate source for understanding what DOE means by its EQ mission is DOE's published strategic plans. These plans include "strategic goals" and "objectives" for its EQ business line, which together define DOE's EQ mission.

SIDEBAR 2.4 EQ STRATEGIC GOAL AND OBJECTIVES FROM DOE'S 1997 AND 2000 STRATEGIC PLANS

The committee was tasked to identify criteria that should be used to evaluate the adequacy of the DOE's EQ R&D portfolio "in the context of EQ strategic goals and mission objectives." As discussed in the text, the EQ strategic goal and objectives in DOE's 2000 strategic plan differ substantively in a number of ways from those in DOE's 1997 strategic plan, which was in effect when the EQ R&D portfolio document was published. For example, the 1997 strategic plan explicitly recognizes the need to "minimize future waste generation," "reduce the most serious risks…first," and "reduce the life-cycle costs of environmental cleanup"—concepts that are missing from the 2000 strategic plan. Despite these and other differences, however, the strategic goal and objectives from both plans clearly focus on problems associated with DOE wastes and contaminated media, and not on the broad interpretation of DOE's "environmental quality" mission.

Providing America with Energy Security, National Security, Environmental Quality, Science Leadership. **U.S. Department of Energy Strategic Plan. September 1997 (DOE, 1997b).**

EQ Strategic Goal: Aggressively clean up the environmental legacy of nuclear weapons and civilian nuclear research and development programs, minimize future waste generation, safely manage nuclear materials, and permanently dispose of the Nation's radioactive waste.

Objective (1) Reduce the most serious risks from the environmental legacy of the U.S. nuclear weapons complex first.

Objective (2) Clean up as many as possible of the Department's remaining 83 contaminated geographic sites by 2006.

Objective (3) Safely and expeditiously dispose of waste generated by nuclear weapons and civilian nuclear research and development programs and make defense high-level radioactive wastes disposal-ready.

Objective (4) Prevent future pollution

Objective (5) Dispose of high-level waste and spent nuclear fuel in accordance with the Nuclear Waste Policy Act as amended.

Objective (6) Reduce the life-cycle costs of environmental cleanup.

Objective (7) Maximize the beneficial reuse of land and effectively control risks from residual contamination.

Strength Through Science: Powering the 21st Century. **U.S. Department of Energy Strategic Plan. September, 2000 (DOE, 2000f).**

EQ Strategic Goal: Aggressively clean up the environmental legacy of gies and institutions to solve domestic and international environmental problems" (DOE, 1997b, p. 24). Taken literally, this would imply that DOE's EQ mission encompasses a wide spectrum of environmental issues (e.g., climate change, biodiversity, ecosystem protection), which as discussed above, is not consistent with the EQ strategic goal and objecobjectives in the same document. Similarly, the EQ R&D portfolio document includes a vision of a significantly expanded future EQ R&D portfolio (termed a "Strategic Portfolio for the 21st Century"), which would include additional R&D investments in areas such as sustainable development and global environmental protection (DOE, 2000b, p. 45). Furthermore, in describing the role of DOE EQ, the document includes the statement that it "provides global leadership to environmental quality efforts" (DOE, 2000b, p. xv). Parts of the 1997 strategic plan and the EQ R&D portfolio document therefore suggest that DOE's EQ mission includes, or should be broadened to include, a myriad of environmental issues beyond DOE wastes and contaminated media.

nuclear weapons and civilian nuclear research and development programs at the Department's remaining sites, safely manage nuclear materials and spent nuclear fuel, and permanently dispose of the Nation's radioactive wastes.

This strategic goal is supported by three objectives:

Objective (1) Safely and expeditiously clean up sites across the country where DOE conducted nuclear weapons research, production, and testing, or where DOE conducted nuclear energy and basic science research. After completion of cleanup, continue stewardship activities to ensure that human health and the environment are protected.

Objective (2) Complete the characterization of the Yucca Mountain site and, assuming it is determined suitable as a repository and the President and Congress approve, obtain requisite licenses, construct and, in fiscal year 2010, begin acceptance of spent nuclear fuel and high-level radioactive wastes at the repository.

Objective (3) Manage the material and facility legacies associated with the Department's uranium enrichment and civilian nuclear power development activities.

Given these major inconsistencies, what is the appropriate scope of DOE's EQ mission? The committee discusses three aspects of this issue. The first is the topical breadth of the EQ mission within DOE. In particular, whether DOE's EQ mission includes (or should be broadened to include) environmental issues within DOE beyond wastes and contaminated media. The second is the temporal breadth of DOE's EQ mission, i.e., whether DOE's EQ mission should focus more extensively on long-term problems or in preventing the occurrence of future problems, rather than simply addressing past problems. The third is the national and international breadth of DOE's EQ mission, i.e., whether DOE's EQ responsibilities should be extended to problems outside DOE, such as those in other agencies or nations. This issue is addressed at the end of Chapter 3 (see "Extending the EQ R&D Portfolio Beyond DOE").

Topical Breadth of DOE's EQ Mission

As discussed above, recent DOE documents have not been consistent in describing the topical breadth of DOE's EQ mission. The EQ strategic goal and objectives in DOE's two most recent strategic plans are quite clear that the topical breadth of DOE's EQ mission is restricted to problems directly related to DOE wastes and contaminated media. However, other parts of the 1997 strategic plan and some parts of the EQ R&D portfolio document suggest that the topical breadth of DOE's EQ mission should be much broader.

Faced with these two very different views, the committee concludes that the more narrow interpretation is more appropriate at the present time. Its reasoning is simple. First, the committee's task explicitly directed the committee to conduct its analysis "in the context of EQ strategic goals and mission objectives," which as discussed above, are quite clear about the topical breadth of the EQ mission. Second, as discussed in Chapter 3, there currently exist a large number of important R&D gaps and opportunities in the EQ R&D portfolio, even within the narrower EQ mission. The committee believes that it would be inappropriate to consider expanding the topical breadth of DOE's EQ mission until the R&D portfolio adequately addresses its current mission. Third, expanding the topical breadth of the EQ mission to include all areas of the environment, such as sustainable development and global environmental protection would create significant overlap with DOE's other missions (in particular, the Energy Resources and Science missions), as well as the missions of other federal agencies with longstanding environmental responsibilities, such as the Environmental Protection Agency, the National Oceanographic and Atmospheric Administration, and the U.S. Geological Survey. Furthermore, such an expansion would make the committee's task nearly impossible, and well beyond the committee's collective expertise.[5]

Conclusion: The EQ mission should continue to focus on problems associated with DOE wastes and contaminated media.

[5] Readers interested in broader environmental R&D needs are encouraged to read a recent NRC report, *Grand Challenges in Environmental Sciences* (NRC, 2000j).

This conclusion does not exclude the possibility that an expanded mission might be warranted some time in the future when the EQ R&D portfolio adequately addresses the important long-term problems that are already within the EQ mission. It also does not lessen the importance of closely coordinating EQ R&D with related R&D efforts by DOE's other business lines. One of the committee's important conclusions in Chapter 3 is that EQ R&D should build upon the R&D activities of, and take into account the needs of, DOE's Science, Energy Resources, and National Nuclear Security business lines.

Finally, the committee believes that some of the inconsistencies described above arise from the fact that DOE uses the term "environmental quality" as the name of its EQ business line. The term environmental quality is used by many federal and state agencies to refer to a much broader spectrum of environmental issues than problems associated with wastes and contaminated media. For example, issues as diverse as climate change, drinking water protection, ecosystem biodiversity, and protection of marine fisheries would be considered part of environmental quality by agencies such as the Environmental Protection Agency, the National Oceanographic and Atmospheric Administration, and the U.S. Geological Survey. The use of the term "environmental quality" as the name of DOE's EQ business line therefore does not reflect its current mission. The committee encourages DOE to change the name of the EQ business line (and its corresponding R&D portfolio) to more accurately reflect the topical breadth of its EQ mission.

Temporal Breadth of DOE's EQ Mission

As discussed earlier, the EQ strategic goal and objectives in DOE's 1997 and 2000 strategic plans are not consistent about the importance of addressing long-term problems or in preventing the occurrence of future problems. Both the 1997 strategic plan (objective 7) and 2000 strategic plan (second half of objective 1) recognize a continuing responsibility in the area of long-term stewardship. The 1997 strategic plan also recognizes the importance of minimizing the generation of new wastes. This concept was not included in the 2000 strategic plan, however. The committee believes that it is important for DOE to strive to prevent the types of contamination and waste management problems that have characterized past DOE activities in ongoing and future DOE operations and facilities by assuring that sufficient environmental considerations and protections are built into them up front.[6]

[6] The Strategic Laboratory Council's adequacy analysis (DOE, 2000g) recognized the importance of reducing the future waste generation when it recommended a new EQ objective to "minimize the risk, volume and cost of newly generated DOE radioactive and hazardous waste."

Although the inclusion of long-term stewardship as an explicit objective of DOE's EQ mission does recognize an important element of DOE's enduring EQ mission, the committee believes that DOE's strategic plans (especially the 2000 strategic plan) still present a rather limited, short-term view of DOE's long-term EQ responsibilities. This short-term view is reflected in DOE's approach to addressing EQ problems. For example, the recent focus of EM has been to meet the ambitious cleanup goals of the 2006 remediation deadlines and legal or regulatory mandates, such as site implementation plans (DOE, 1998). It is important to recognize, however, that EM's definitions of cleanup for the great majority of DOE sites has meant "securing sites" and "minimizing exposures"—but not rendering the sites suitable for unrestricted use (see Sidebar 1.2; NRC, 2000a). In reality, radioactive and other wastes will remain at most DOE sites even after achieving the cleanup goals, and over 100 sites will require some form of long-term stewardship to protect human health and the environment after they have been closed (NRC, 2000a; DOE, 1999, 2001 b). Furthermore, DOE's most contaminated sites with the largest quantities of wastes and contaminated media (e.g., Hanford, Washington; Idaho National Engineering and Environmental Laboratory; Savannah River, South Carolina) will not achieve closure for decades (DOE, 2000e; see Sidebar 2.1).

Similarly, the focus of RW has been to assess the site suitability for licensing of the proposed Yucca Mountain repository by 2010. This short-term emphasis has enabled RW to develop a technical base for determining whether the Yucca Mountain Site could be a suitable geological repository, but generally has not looked beyond licensing to address environmental science, engineering, and social science issues that will arise during the licensing and operation of the repository. For example, improved understanding of the performance of the waste packages within the geological environment and novel monitoring techniques are needed during the pre-closure period, which will last from decades to more than a century.

Although the short-term focus of EM and RW has provided a means for making progress on some short-term elements of the EQ mission, it also may have been misinterpreted by some decision makers to mean that DOE's EQ mission will be essentially completed by 2006 or 2010, i.e., a "going out of business within the next decade" view of DOE's EQ mission. Here the committee needs to explain what it means by the phrase "going out of business within the next decade," because as indicated above, in some respects a going out of business attitude is appropriate for large parts of the EQ business line, and thus for a proportional part of its supporting R&D portfolio. This is because DOE is responsible for sites and materials that today pose serious risks to health and the environment. Thus DOE must act with urgency to mitigate these risks as soon as possible. DOE must put as many as possible of these risks "out of business", e.g., perhaps mitigating the risks by cleaning up a site, or by isolating nuclear wastes in a well-designed repository. It is in this sense, for these treatable risks, that a going out of business attitude is appropriate; EQ's overall mission is to put itself out of business by addressing past problems, and by anticipating and preventing future problems.

However, at present there exists no adequate technology to address other risks, including some of the worst risks. For these, DOE needs parallel programs of long term stewardship and as-long-term-as-necessary R&D to find solutions. And a sense of urgency with respect to these programs is needed in order to protect public health and the environment. Nevertheless, for these risks the sense of urgency does not imply going out of business at any time in the near future. It rather implies getting on with what can be done now, which here is long-term stewardship and R&D. To recapitulate, because DOE faces many serious risks to health and environment, and because some of the worst risks are now unsolvable, the agency must cultivate a balanced sense of urgency, proceeding with deliberate speed to mitigate those risks it can in the short term, and in parallel to initiate R&D on solutions for the currently intractable problems so that in the long term their risks also are addressed. Where this report refers to "going out of business within the next decade," the committee is referring to a mistaken attitude or belief that all EQ problems will be handled in the relatively near future, and the DOE EQ mission completed at that point.

As one might expect, the short-term focus also has had a major impact on DOE's approach to EQ R&D. One of the most consistent and important findings of two recent analyses of DOE's EQ R&D portfolio is that it lacks a long-term strategic vision (DOE, 2000g,h; see also Appendix C). This issue will be discussed at length in Chapter 3.

Finding: A "going out of business within the next decade" view of DOE's mission has served to obscure DOE's long-term EQ responsibilities and has done little to address DOE's most challenging EQ problems.

Recommendation: DOE should develop strategic goals and objectives for its EQ business line that explicitly incorporate a more comprehensive, long-term view of its EQ responsibilities. For example, they should emphasize long-term stewardship and the importance of limiting contamination and materials management problems, including the generation of wastes and contaminated media, in ongoing and future DOE operations.

The committee's statement of DOE's "EQ challenges" could be used as the basis for these revised strategic goals and objectives.

3

A LONG-TERM VISION FOR DEPARTMENT OF ENERGY ENVIRONMENTAL QUALITY RESEARCH AND DEVELOPMENT

The U.S. Department of Energy (DOE) has taken a first, important step toward integrating its research and development (R&D) programs through portfolio analysis. In so doing, it has recognized the short-term emphasis of the Environmental Quality (EQ) R&D portfolio, and has requested this study to provide strategic advice on how it could build a more effective EQ R&D portfolio. In this chapter, the committee first discusses the important functions of an EQ R&D portfolio, including the associated national and international contexts. The committee then uses these descriptions and the accompanying findings, conclusions, and recommendations to develop a set of criteria to evaluate the adequacy of the portfolio. Finally, the committee discusses five broad themes that DOE could use as "principal elements" of its EQ R&D portfolio. In sum, this chapter represents the committee's vision of a more effective portfolio of activities that incorporates a more "life-cycle based" (i.e., systematic consideration of the entire expected life-cycle of a technology or facility, from initial design, through operation, to closure and long-term stewardship) approach to DOE's EQ problems and moves beyond the short-term, "going-out-of-business within the next decade" philosophy that has driven DOE's EQ R&D to focus on short-term needs over the last decade.

IMPORTANT FUNCTIONS OF AN EFFECTIVE EQ R&D PORTFOLIO

An effective long-term R&D portfolio could contribute to DOE's EQ mission in a number of important ways. Effective EQ R&D also should contribute significantly to DOE's other missions. In this section, the committee describes the following functions that are considered essential for an effective, long-term EQ R&D portfolio:

- addressing long-term, currently intractable[1] EQ problems;
- Improving performance, reducing risks to human health and the environment, decreasing cost, and advancing schedules;
- advancing more informed EQ decision making;
- making informed decisions on nuclear energy;
- promoting national security;
- helping to bridge the gap between R&D and application;
- supporting research and training in relevant fields of science and engineering;
- leveraging results from DOE's Office of Science; and
- leveraging and supporting relevant R&D programs outside DOE.

Addressing Long-Term, Currently Intractable EQ Problems

The problems confronting the EQ business line are long-term, both because they involve materials that in some cases remain hazardous for thousands to hundreds of thousands of years and because they pose scientific questions that are so complex and unique that R&D will have to continue for decades to generate their solutions.[2] This uniqueness and complexity demand that the EQ R&D portfolio have a strong, if not dominant, long-term component. As discussed in Chapter 2, this contrasts markedly with the current short-term emphasis of DOE's EQ R&D portfolio. In this section, the committee describes some important long-term EQ problems.

One of the most important long-term EQ challenges is long-term stewardship of legacy waste sites for which cleanup is complete but that have residual risks to human health and the environment. As discussed in Chapter 1, radioactive and other wastes will remain at most sites even after achieving the cleanup goals, and active stewardship activities to protect human health and the environment from hazards will be required for long or indefinite time periods (see Sidebar 3.1; DOE, 1999a). One of the most important problems associated with long-term stewardship is the lack of adequate long-term institutional management capabilities, which will require long-term scientific, technical, and social science R&D (NRC, 2000a). Furthermore, DOE's largest sites will require decades to reach their stated cleanup goals (see Sidebar 2.1). Many of the important EQ problems facing DOE at these sites currently have no acceptable, identified solution and will require sustained R&D efforts well beyond

[1] The committee uses the term "currently intractable" to refer to problems for which there are no identified, acceptable solutions but for which long-term R&D could lead to such solutions.

[2] When the expression "long-term R&D" is used in this report, the committee means "long-term" from both of these perspectives.

2006 (see Sidebar 3.2). For example, proposed solutions for the treatment of high level waste are still being developed (see Sidebar 3.3). In sum, many of DOE's waste management and disposal problems currently are, and will continue to be, intractable during the active clean-up

SIDEBAR 3.1 LONG-TERM STEWARDSHIP OF LEGACY DOE SITES

Because of the size and complexity of cleanup operations, the life-cycle costs to close DOE sites is now estimated to be $168–212 billion (estimated costs from FY 1997 to 2070 in constant 1999 dollars), and closure at the largest sites will not be completed until as late as 2050 (DOE, 2000e; NRC, 2000a). The term "closure," however, is a misnomer. Even after DOE sites are closed, 129 of them will require continued, long-term surveillance and maintenance, which will include controlling releases from sites, limiting access, and maintaining public records and site markers (DOE, 1999a, 2001 b; NRC, 2000a). DOE's responsibilities, and thus financial burdens, for long-term stewardship of these sites will persist for the indefinite future, as will the potential risks to the public and the environment. DOE estimates that it currently spends approximately $64 million annually on long-term stewardship activities, and these costs will increase to nearly $100 million annually by 2050, when all sites are expected to be closed (DOE, 2001 b).

The hazards associated with DOE sites and facilities will not be eliminated at any time in the near future (DOE, 1999a). In many cases, such as closed high-level waste tanks, radioactive waste disposal sites, and test and production facilities, the hazards will persist for many thousands of years. The unprecedented scale and longevity of the problems create a host of challenges, such as maintaining records over thousands of years, maintaining control of, and monitoring sites indefinitely, and developing a process for regularly reevaluating the status of the sites and addressing problems when they occur. In order for the sites to be safeguarded effectively over such long timeframes, new technologies will be required and will need to be continually upgraded as technological advancements are made—particularly when risks and costs can be significantly reduced. If the last two decades are at all indicative, for example, information storage will change dramatically over the next hundred years, let alone the next thousand years. It will be essential that data concerning DOE sites be stored in a fashion, and upgraded as necessary, to ensure that it can be accessed far into the future.

The long-term nature of the hazards at DOE sites also means that technologies, societal values, economics, standards, and politics are likely to evolve substantially before environmental remediation and radioactive materials problems are resolved. It will therefore be necessary to use methods that, to the maximum extent possible, will allow subsequent actions to be taken to further stabilize, remediate, or treat materials to reduce risks to the environment and public. This approach requires substantial investment in EQ R&D to ensure that an enduring program is in place to take advantage of future technological developments.

period. A strong continuing R&D portfolio therefore is essential, and may be more important after cleanup than before.

SIDEBAR 3.2 REMEDIATING AND MONITORING GROUNDWATER CONTAMINATION AT THE HANFORD SITE

Approximately 1.2 billion cubic meters of groundwater is contaminated with radioactive, hazardous, and toxic substances under the Hanford Site in eastern Washington (DOE, 1997a). In the near term, concerns have been raised about heavy metals, such as chromium, reaching the Columbia river in sufficient quantities to threaten salmon spawning grounds. Concerns also have been raised that, in the longer term (i.e., more than 100 years), substantial quantities of radioactive substances could reach the river and pose significant risks to the environment and local populations.

At present there is no cost-effective means of remediating such a large volume of groundwater, and methods for limiting underground transport are hardly better. Further R&D in the areas of hydrogeology, treatment and extraction technologies, and monitoring will be essential to protect the environment and local populations in the long term. The National Research Council is currently reviewing the Hanford Site's science and technology program for contamination problems associated with the vadose zone and groundwater. A report recommending ways to improve the technical merit and relevance of this program is expected to be released during the summer of 2001.

Similarly, there are significant uncertainties and major technical and social science challenges associated with investigating and developing geological repositories for high-level waste and spent nuclear fuel (NRC, 2001). For example, improved understanding of the performance of the waste packages within the geological environment and novel monitoring techniques are needed during the pre-closure period, which is expected to last from decades to several centuries for Yucca Mountain. Such long-term R&D could help ensure that the repository is operating effectively and could allow the repository design to be refined during the pre-closure period to improve its performance and/or reduce costs. Similarly, long-term R&D could help identify and implement measures to build public confidence in repository performance during the pre-closure period.

In summary, the short-term emphasis of EQ R&D efforts described in Chapter 2 and the declining budget trends discussed in Chapter 5 are fundamentally inconsistent with the long-term nature of the problems the EQ business line must address. DOE is responsible for managing, removing (or isolating), and disposing of uniquely hazardous, chemically complex substances, such as spent nuclear fuel, liquid high-level radioactive wastes, and mixtures of hazardous and radioactive compounds. It is also responsible for remediating a wide range of contaminated media and facilities (e.g., groundwater, soil, and nuclear production facilities).

These activities must be carried out under a wide range of challenging and often unique circumstances. In many cases, environmental remediation, management, and disposal of hazardous and radioactive substances require development of innovative technologies. Environmental cleanup, waste management, and disposal activities will, of necessity, endure for generations, and long-term stewardship at most sites could continue indefinitely thereafter. Therefore, the future can provide opportunities for continual improvements in the methods used to address these issues and the possibility of breakthrough technologies that could greatly reduce the risks to human health and the environment and the costs to future generations.

SIDEBAR 3.3 DEVELOPMENT OF TREATMENT AND SOLIDIFICATION METHODS FOR HIGH-LEVEL WASTE AT THE SAVANNAH RIVER SITE

Treatment and solidification of high-level radioactive waste derived from the production of plutonium and other special nuclear materials is one of the most challenging problems confronting DOE. The Savannah River site stores 120,000 cubic meters of intensely radioactive and chemically complex high-level waste (DOE, 1997a; NRC 2000f). Development of a treatment process has required research into a one-of-kind system and extensive supporting research and engineering.

DOE spent over a decade developing a process (in-tank precipitation) to remove actinides, strontium, and cesium from the high-level waste salt in order to reduce the number of waste canisters that would be produced and sent to a geologic repository for disposal. Despite years of effort and an expenditure of almost $500 million, however, DOE recently was forced to abandon this approach because it did not work as planned (NRC, 2000f). Prior to this decision, EM's Office of Science and Technology had supported some R&D on alternatives to in-tank precipitation. Although limited, this R&D helped DOE initiate a major R&D effort on alternative technologies to ensure that the waste salt processing could proceed in an efficient and reliable manner.

Finding: Many of the problems confronting the EQ business line are long-term, both because they involve materials that in some cases remain hazardous for thousands to hundreds of thousands of years, and because they are so complex and unique that R&D will have to continue for decades to generate their solutions.

Conclusion: The uniqueness and complexity of DOE's EQ problems demand that the EQ R&D portfolio have a strong, if not dominant, long-term component.

Recommendation: DOE should begin to devote an increasing fraction of its EQ R&D to long-term problems to ensure that an R&D portfolio dedicated to long-term problems is in place within five years.

Conclusion: The technical and social complexities associated with nuclear materials handling, storage, waste management, and disposal demand a clear long-term vision.

Recommendation: DOE should develop a long-term strategic vision for its EQ R&D portfolio. This vision should provide the framework for developing the science and technology necessary to address EQ problems that extend beyond the present emphasis of short-term "compliance" and should incorporate the principle of continual improvement.

The importance of long-term EQ problems does not mean that DOE should focus its EQ R&D efforts exclusively on long-term problems. Short-term R&D should be undertaken to address near-term problems, such as those driven by legal and regulatory requirements (e.g., cleanup of contaminated groundwater, see discussion in NRC, 1999b). It is essential, however, that the anticipated timeframe of such R&D (i.e., when results can be expected) be consistent with the short timeframe of such problems. Long-term R&D should not be undertaken on problems that will be addressed in the near term.

Improving Performance, Reducing Risks to Human Health and the Environment, Decreasing Cost, and Advancing Schedules

The type of problem-driven R&D envisioned as part of DOE's EQ R&D portfolio should be viewed as an investment (see discussion in Chapter 4). The results should be expected to improve performance, reduce risks to human health or the environment, decrease costs, or advance schedules. Successes and failures should be closely monitored and additional investment made if R&D has paid off well.[3] Failure of past levels of R&D to pay off is an indication that one or more of the following may be true: The portfolio was not balanced, the program was poorly managed, the funding was too high, the wrong researchers were involved, or the evaluation was premature (i.e., taking place before R&D results have been realized). Furthermore, an R&D portfolio that rewards

[3] The success or failure of a new technique or method in achieving one or more of these objectives is directly related to whether the R&D results are "deployed" in the field. Deployment is necessary but not sufficient for success, as some deployments may not improve performance, reduce risks, decrease costs, or advance schedules.

innovation in solving current problems that are extremely challenging or unacceptably expensive will have a certain number of marginal successes or outright failures. That is among the signs that an R&D program is healthy and pushing the cutting edge of science and technology. Furthermore, knowledge gained through R&D failures can be very useful. Even so, an important measure of the long-term success of the R&D portfolio is the degree to which it has led to improved performance, reduced risks to human health or the environment, decreased costs, and advanced schedules.

Although these four objectives can be used as a measure of the success of the EQ R&D portfolio, the types and timeframes of R&D need to be considered when identifying appropriate metrics for success of individual projects. Long-term R&D (especially fundamental research) often carries inherently greater risks, can take many years to come to fruition, and can result in benefits in unexpected applications. It would be a mistake to expect all research to lead to demonstrable results in a very short time, or to avoid the risk of failure by excluding R&D to address particularly challenging problems. The success of long-term research projects can be evaluated periodically through peer review (COSEPUP, 1999b; NRC, 1998); whereas the success of more applied R&D projects can be evaluated through relatively direct measurements (COSEPUP, 1999b), such as the development of a new technology that is more effective, less costly, or more time efficient than earlier technologies. Different types of R&D carry with them differing expectations, and it is important in evaluating success to calibrate expectations to the type of work being done.

Conclusion: Careful analysis of the success and failures of R&D over time is an important consideration in evaluating the adequacy of the EQ R&D portfolio and in determining an appropriate level of EQ R&D investments.

Recommendation: DOE should institute a program to analyze periodically the impact of the R&D portfolio and should take into account the success of past R&D investments in making future R&D funding decisions.

These analyses should not preclude R&D with a significant risk of negative results if the potential gain is substantial. Metrics for the portfolio as a whole should include measurements of the degree to which it has led to improved performance, reduced risks to human health and the environment, decreased costs, and advanced schedules. Metrics for individual projects should reflect the differing objectives and timeframes of various R&D projects, such as fundamental research and applied R&D. Such metrics should be developed with input from independent experts such as the advisory group recommended later in this report (see Chapter 4).

Advancing More Informed EQ Decision Making

In many cases, the availability of improved information and scientific, technical, and social understanding can lead to more informed decision making. For example, more efficient and cost-effective technologies based on improved technical understanding could reduce the costs of remediating contaminated DOE sites. However, numerous decisions on environmental remediation, waste management, materials storage, and facility decommissioning involve complex technical issues for which there are only limited data and partial scientific understanding. Recent studies have identified major gaps in scientific and technical understanding related to EQ problems, including subsurface science (NRC, 2000c; DOE, 2000g), the complex chemical dynamics in high-level waste (NRC, 2000d; DOE, 2000g), corrosion rates for materials used for long-term storage and disposal of high-level waste (NRC, 2000d; DOE, 2000g), and the mobility of certain heavy metals in surface and groundwater (NRC, 1999b; DOE, 2000g). These knowledge gaps affect DOE's decision-making in a number of important areas, including the following:

- understanding fully the risks to human health and the environment that are associated with DOE wastes and contaminated media;
- determining the magnitudes and types of technical, scientific, and social uncertainties with which DOE programs contend;
- balancing effectively the risk and rewards of various options for cleanup, end states, storage, treatment, and stewardship of hazardous, toxic, or radioactive materials (i.e., life-cycle analyses);
- avoiding or minimizing environmental harm and risks to human health that are associated with meeting national security responsibilities; and
- addressing environmental remediation and long-term stewardship responsibilities associated with existing or future national and international energy needs.

In short, there is an array of issues, ranging from disposal of high-level waste to remediation of environmental contaminants to construction of new research facilities for ongoing defense programs, that could benefit from further EQ R&D underpinning defensible, enduring decision making.

It should be emphasized, however, that lack of technical information does not necessarily preclude effective decision making. Current decisions must consider that technology and understanding can be expected to improve considerably during the long timeframes of some EQ chal lenges. For residual contamination at closed legacy sites, for example, the system of long-term stewardship put in place should not preclude future actions to address remaining risks to human health and the environment (see Sidebar 3.1). The system should allow future decision makers to re-initiate active cleanup activities if and when future technologies or understanding develop to a point where it makes sense to address remaining risks (NRC, 2000a), or when the understanding of the risks to human health and the environment improves. For geological disposal of high-level wastes and spent nuclear fuel, DOE should pursue a phased approach that would allow changes to the disposal plans to improve operations, safety, and schedule or reduce cost throughout the decades-long process of emplacement (see Sidebar 3.4). Such a phased decision making process[4] also was recommended for dealing with high-level waste problems at the Hanford Site (NRC, 1996b), and could be applied to a number of the most important long-term EQ problems.

In addition to filling science and technology gaps, effective long-term R&D programs also support R&D on technical alternatives when existing techniques are expensive, inefficient, or pose high risks to human health or the environment, or where techniques under development have high technical risks[5] (NRC, 1999a; DOE, 2000g). Several recent studies have found that the EQ business line has not adequately supported such R&D in the past, and have recommended that strategic R&D on technical alternatives be added to the portfolio (NRC, 1999a; DOE, 2000g). When information is inadequate to make the decision desired, i.e., to choose between major policy options, one can seek more information in two ways. The two paths can be taken in parallel or as alternatives, depending on the policy situation. One is to initiate R&D (perhaps postponing the decision). Global climate change illustrates this option. The second is to take a more modest decision that may yield more information (i.e., "experience") and which leaves open the major policy options. This latter approach does not preclude initiating R&D in parallel.

<u>Finding</u>: Numerous decisions on environmental cleanup, waste management, materials storage, and facility decommissioning involve complex technical issues for which only limited data and partial scientific understanding exist.

<u>Conclusion</u>: The EQ R&D portfolio is critical to improving decision making and should be designed to help inform important DOE decisions, including support for technical alternatives in areas of high cost or high risk.

[4] Also commonly referred to as "adaptive management."

[5] Technical risk is defined as "the probability that the technique or method fails to accomplish the goals and performance requirements set by policy or regulation"

SIDEBAR 3.4 A FLEXIBLE APPROACH TO THE DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE AND SPENT NUCLEAR FUEL

One of the most difficult of DOE's EQ challenges is the need to develop, open, and operate unique, first-of-a-kind facilities for the permanent disposal of radioactive spent fuels and high-level wastes. In 1990, the National Research Council's Board on Radioactive Waste Management published a report, *Rethinking High-Level Radioactive Waste Disposal,* which suggested that DOE adopt a flexible and experimental institutional approach to this challenge. In particular, the report described a strategy that acknowledges the following premises:

- *Surprises are inevitable in the course of investigating any proposed site, and things are bound to go wrong on a minor scale in the development of a repository.*
- *If the repository design can be changed in response to new information, minor problems can be fixed without affecting safety, and major problems, if any appear, can be remedied before damage is done to the environment or to public health.*

This flexible approach can be summarized in three principles:

- *Start with the simplest description of what is known, so that the largest and most significant uncertainties can be identified early in the program and given priority attention.*
- *Meet problems as they emerge, instead of trying to anticipate in advance all the complexities of a natural geological environment.*
- *Define the goal broadly in ultimate performance terms, rather than immediate requirements, so that increased knowledge can be incorporated in the design at a specific site.*

In short, this approach uses a scientific approach and employs modeling tools to identify areas where more information is needed, rather than to justify decisions that have already been made on the basis of limited knowledge. (NRC, 1990, p. 7)

Making Informed Decisions on Nuclear Energy

Today it is not clear how and by which technologies the current problems facing nuclear energy may be resolved. What actually happens will depend on how safety, waste disposal, and proliferation concerns are resolved, and whether the greenhouse debate adds increasing importance to nuclear energy's "carbon benignness." (NASA, 1995, p. 62).

Decisions about the future of nuclear power as an energy source in the United States may be affected by the R&D required for proper management and subsequent disposal of commercial spent nuclear fuel in a geological repository. Whereas successful completion of a repository will not ensure a significant future role for nuclear energy as a power source in the United States, lack of a successful program could endanger or prohibit it.

Elements of DOE's EQ R&D portfolio could lead to reductions in the risks and uncertainties associated with the disposition of spent nuclear fuel. New technologies, for example, could improve the engineered package design for containing spent nuclear fuel in a repository (e.g., through containers with longer lifetimes) or reduce the quantity of fuel to be disposed of (e.g., through higher burn-up[6] fuel) (DOE, 2000k). If and when a license application is submitted to the Nuclear Regulatory Commission, the Office of Civilian Radioactive Waste Management plans to decrease its R&D spending to a level sufficient to support performance confirmation activities at Yucca Mountain. Additional long-term R&D could allow the repository design to be refined during the pre-closure period to improve performance or reduce costs. Similarly, long-term R&D could help identify and implement measures to build public confidence in repository performance during the pre-closure period. The magnitude of the uncertainties and the long-term nature of the potential risks associated with a geologic repository demand that extensive R&D continue long after the facility is opened (NRC, 1990).

Finding: Decisions about the future of nuclear power as an energy source in the United States may be affected by the R&D required for proper management and subsequent disposal of commercial spent nuclear fuel in a geological repository.

Conclusion: Long-term R&D during the pre-closure period could lead to improved repository performance or reduced costs, and could help build public confidence in repository performance.

Recommendation: A significant program of long-term R&D to improve repository design and operations and to identify and implement measures to build public confidence in repository performance should continue long after a repository is opened.

When considering future emphases for the EQ R&D portfolio, it is important to consider the impact of R&D carried out as part of DOE's

[6] The term "burn-up" refers to the energy output per unit mass of fuel. In general, the higher the burn-up the lower the amount of fuel that will be necessary to generate a given amount of energy.

Energy Resources business line, which is designed to promote the development and deployment of energy systems and practices that will provide current and future generations with energy that is clean, efficient, reasonably priced, and reliable (DOE, 2000f). Although such R&D is not part of the EQ portfolio, it is generally relevant to DOE's EQ mission because of its potential impact on the environmental effects of different energy sources (including nuclear power) and the overall demand for energy in the United States. Such R&D could affect future demands for nuclear power and, as a result, change future projections of the quantities and characteristics of associated wastes and contaminated media.

DOE's Nuclear Energy Research Advisory Committee recently issued a long-term Nuclear Technology R&D Plan (DOE, 2000k) to address technical issues associated with the safety and economics of future applications of nuclear energy. The plan outlines a number of long-term goals for DOE's nuclear energy R&D programs in the following areas: basic research, plant operations and control, nuclear power R&D, isotopes and radiation sources, and space nuclear power systems R&D. R&D on future nuclear power systems, such as extended burn-up of fuel in nuclear power plants, could have a major direct impact on DOE's EQ responsibilities. Issues of particular importance include evaluating the effects of extended burn-up on spent fuel production, storage, transportation, and disposal and how to determine whether such spent fuel can meet waste acceptance criteria for a repository or affect repository licensing and performance.

Although the Nuclear Energy's Research Advisory Committee's long-term R&D plan did not explicitly consider R&D to address the environmental legacies of nuclear power systems and nuclear weapons production, it did emphasize the importance of considering the environmental consequences of future nuclear power systems: "Perhaps the most important point is that all future nuclear energy programs should include a focus on environmental protection from the beginning of the program" (DOE, 2000k, p. 56). It is essential to adopt such a life-cycle approach to the environmental consequences of future nuclear power technologies (i.e., from initial design, through waste production and disposition, to deactivation and decommissioning of the systems at the end of their design life). Elements of DOE's Energy Resources R&D portfolio therefore are directly relevant to DOE's EQ mission.

<u>Finding</u>: DOE's R&D on future nuclear power systems could have significant impact on future EQ responsibilities by affecting projections of the quantities and characteristics of associated wastes and contaminated media.

<u>Recommendation</u>: DOE should adopt a life-cycle approach to the waste and contamination that could result from future nuclear

power sources in order to integrate EQ R&D with relevant Energy Resources programs.

Promoting National Security

With the end of the Cold War, national security and non-proliferation objectives led the United States to weapons dismantlement and cessation of weapons testing. This gave rise to dramatically new nuclear materials stewardship responsibilities for the United States and other countries, especially Russia. These new responsibilities, in turn, have changed U.S. needs regarding the storage, processing, possible uses, waste management, and disposal of excess special nuclear materials. In response, DOE established the National Nuclear Security business line, which is designed to enhance national security through the military application of nuclear technology and reduce the global danger from weapons of mass destruction (DOE, 2000f).

There are a number of potential benefits from a successful EQ R&D effort that can have major impacts on the success of DOE's national security mission. The National Nuclear Security business line has six objectives, including two that are directly relevant to the EQ business line:

- reduce the global danger from the proliferation of weapons of mass destruction; and
- ensure that DOE's nuclear weapons, materials, facilities, and information assets are secure through effective safeguards and security policy, implementation, and oversight.

Successfully meeting these goals will require close collaboration with the EQ business line. Reducing nuclear weapon stockpiles requires facilities and operations that could create new environmental problems, and the environmental and waste management aspects should be considered up front in program decisions. For example, an option that minimizes wastes or results in wastes that are in a better form for disposal might be preferable to one that is perhaps a little cheaper but leaves a bigger waste management or facility cleanup problem. These nuclear materials, regardless of their origin, will need to be managed, processed, stored, transported, and ultimately disposed of permanently. National security interests are directly affected by, for example, EQ R&D on processes that could be used to dispose of surplus plutonium by immobilizing it for disposal in vitrified high-level waste (DOE, 2000c).

Without effective EQ R&D, the disposition of materials arising from the dismantlement of nuclear weapons could be impeded, undermining national security. This issue illustrates the importance of effective linkages among different DOE program units (Offices of Environmental

Management [EM]; Civilian Radioactive Waste Management; Nuclear Energy, Science and Technology; and the Office of Fissile Materials Disposition) and R&D portfolios (EQ, National Nuclear Security, and Energy Resources). The success of DOE's national security mission, therefore, is dependent upon DOE's EQ mission, which requires that the latter have an effective long-term R&D program.

Finding: There are a number of potential benefits from a successful EQ R&D effort that could have a significant impact on U.S. national security.

Conclusion: DOE's R&D planning efforts should consider the value of EQ R&D to DOE's national security mission and the potential impacts on EQ R&D requirements arising from national security mission decisions.

Helping to Bridge the Gap Between R&D and Application

Outside reviews have found that information and technologies developed by the EQ R&D portfolio often are not promptly used in the field by DOE contractors. In a 1997 NRC report on DOE's Environmental Management Science Program (EMSP), for example, the committee found that the movement of new knowledge and insights from investigators to full-scale application is a slow and diffuse process (NRC, 1997). A number of reports from the U.S. General Accounting Office have discussed problems that have hindered the movement of technologies developed and demonstrated within EM's Office of Science and Technology into the field (GAO, 1996, 1998). The problem of achieving effective implementation of new technologies is not unique to DOE (e.g., NRC [2000b] discusses this problem in the area of weather prediction), and its causes are numerous and widespread.

Several factors specific to DOE exacerbate the problem of deploying new or novel technologies.

1. At many sites cleanup proceeds under operational contracts that do not provide any incentive for contractors to adopt new technologies— in fact, contractors' incentives often run counter to adopting new technologies that accelerate a project, because the longer a contract lasts the more it is worth (NRC, 1999b).
2. Legal or regulatory requirements may, for good reasons, specify a certain technological approach or timetable for cleanup actions. Prescribing a particular technology or schedule, however, can effectively foreclose innovation.

3. Political pressures may prompt or prevent deployment of technologies—regardless of whether they make sense technically.
4. New technologies may remain unused because site managers prefer well-established technologies, because they are familiar with them and because they are unwilling to accept the higher risk of violating legally mandated schedules attendant with adopting novel approaches.
5. Technology transfer is frequently impeded by weak feedback channels between EQ R&D and operational personnel (DOE, 2001 a). For example, one of the principal channels used in EM, the Site Technology Coordination Groups,[7] have been criticized as being overly formal, complex, cumbersome and slow, and focused more on developing new projects than promoting effective coordination and deployment (NRC, 1999a).

These factors have a common theme: Constraints beyond and distinct from the specific EQ problem being addressed override the motivation to deploy technologies derived from EQ R&D. In some instances, the causes are outside the control of EQ R&D managers (e.g., contractual requirements); in others, R&D managers could act to reduce the disconnect that arises between R&D and deployment (e.g., improving contacts with future users to ensure deployments). In either case, EQ R&D must remain focused on the real problems, while at the same time DOE management must develop effective mechanisms to eliminate or at least buffer the EQ R&D portfolio against systemic impediments such as contractor parochialism and contractual disincentives.

The discussion above touches on many reasons why R&D often is not applied in the field. The particulars vary from site to site and case to case. Accordingly, the remedies may be many and varied. One potential approach to this problem would be to explore a variety of remedies on an experimental (e.g., limited and reversible) basis at a variety of sites. The success of each would be monitored and evaluated, and results documented and disseminated. In this way a set of validated approaches could be developed which could be modified for local situations and adopted as appropriate. Such an approach builds on local experience to avoid the common "one size fits all" failure.

<u>Finding</u>: Information and technologies developed in the EQ R&D portfolio often are not promptly used in the field by DOE contractors.

[7] EM's Office of Science and Technology formed Site Technology Coordination Groups at each major site to interact with local contractor personnel and others to obtain that site's environmental restoration and waste management technology needs.

Conclusion: The gap between R&D and application has many causes, some of which can be addressed by EQ R&D managers while others are outside their control.

Recommendation: DOE's EQ R&D managers should provide continual feedback to users (and accept input from users) and include sufficient funds and incentives to improve application of R&D results where they will solve EQ problems.

Supporting Research and Training in Relevant Fields of Science and Engineering

A strong EQ R&D portfolio requires technically skilled individuals. Research and training programs in nuclear engineering, radiochemistry, and related fields of science and engineering have been decreased substantially in recent decades (DOE, 2000k). An effective, adequately funded R&D portfolio that includes new starts, extensions of promising R&D, and periodic new initiatives has the potential to promote the development of the future nuclear and environmental scientists and engineers required to address the long-term problems described in this report. For example, undergraduate and graduate students with an interest in environmental and nuclear fields (and their advisors) must view the EQ R&D portfolio as providing sustained support for "cutting edge" R&D to address important national problems. The portfolio needs to attract and retain a cadre of top-quality researchers in academia and the national laboratories who are knowledgeable and committed to DOE's R&D needs, and help support the students, postdoctoral associates, and faculty necessary for the enduring mission. In addition, DOE needs to help develop people with practical training in the handling of hazardous materials, operation of facilities containing such materials, packaging, and transportation.

As discussed earlier, DOE's EQ strategic objectives have not been consistently and clearly articulated in high-level DOE planning documents (see discussion in Chapter 2). To attract and retain top-tier scientific and engineering talent, the R&D portfolio must have a clear vision and stable funding. Enhancing the stability of funding could be achieved by a variety of means, such as ensuring that new funding cycles occur on a regular, if not annual, basis and by making longer-term grants available to researchers. Issues associated with R&D funding levels are discussed more fully in Chapter 5.

Finding: Research and training programs in relevant fields of science and engineering have been substantially reduced in recent decades.

Conclusion: An effective and adequately funded EQ R&D portfolio that includes new starts, extensions of promising R&D, and periodic new initiatives could promote the development of the future scientists and engineers required to address DOE's long-term EQ problems.

Recommendation: The EQ R&D portfolio should include stable support for research and training in relevant fields of science and engineering, including periodic new initiatives on important EQ problems.

The R&D centers recommended in Chapter 4 would be a good way to develop such people. It should be noted, however, that the EQ R&D portfolio cannot be expected to provide all of the support that is necessary to develop the future scientists and engineers to address DOE's long-term EQ problems. One of the objectives of DOE's Science business line is to provide the "scientific workforce…that ensures success of DOE's science mission and supports our Nation's leadership in the physical, biological, environmental, and computational sciences" (DOE, 2000f, p. 7). Therefore, DOE's Office of Science also could be expected to help meet these needs. Other important sources of federal support for research and training in relevant areas of science and engineering include the National Science Foundation, the Environmental Protection Agency (EPA), and the Department of Defense.

Leveraging Results from DOE's Office of Science

DOE's Science business line is dedicated to "advanc[ing] the basic research and instruments of science that are the foundations for DOE's applied missions, a base for U.S. technology innovation, and a source of remarkable insights into our physical and biological world and the nature of matter and energy" (DOE, 2000f, p. 7). The Science business line funds basic research in four central areas: (1) fueling the future (clean and efficient energy sources), (2) protecting our living planet (environmental impacts of energy production); (3) exploring matter and energy, and (4) extraordinary tools for extraordinary science (e.g., multidisciplinary research).

DOE's 2000 strategic plan also directs the Office of Science (SC) to "support long-term environmental cleanup and management at DOE sites…." (DOE, 2000f, p. 7). SC includes a number of basic research programs that are related to DOE's EQ mission (see Table 3.1), particularly in its Office of Basic Energy Sciences (BES) and the Office of Biological and Environmental Research (BER). Among other programs, the BES supports projects to improve current understanding and to mitigate the environmental impacts of energy production (DOE, 2000b). Areas of particular importance to the EQ R&D portfolio include the geoscience, separations science, and materials science and engineering research programs. The BER focuses on research designed to advance environmental and biomedical knowledge connected to energy (DOE, 2000b); examples of areas of relevance to the EQ R&D portfolio include the Natural and Accelerated Bioremediation Program and the Environmental Molecular Sciences Laboratory.

It is important to recognize that although some SC research is relevant to EQ R&D, the main drivers for most SC research are not EQ problems or the problems addressed by DOE's other mission areas. Rather, SC's research is inherently "basic" (i.e., it looks within science for its research questions and justifications). Put another way, SC sees research as an end in itself, but for EQ research is a means to an end. These different world views make cooperation and coordination difficult, and unlikely without conscious, continual effort. The EMSP program, which has been noted as making important research contributions by a number of recent studies (DOE, 2001a; NRC, 2000c, 2001d,e) demonstrates that such cooperation and coordination are possible.

Finding: Significant elements of DOE's Science portfolio are directly related to components of the EQ R&D portfolio.

Conclusion: Relevant research supported by DOE's Office of Science should be integrated and coordinated with EQ R&D.

Leveraging and Supporting Relevant R&D Programs Outside of DOE

To provide a broader context and as part of its task to consider whether the EQ R&D portfolio should incorporate related issues outside DOE, the committee considered relevant R&D programs in other agencies, the private sector, and other nations. The committee gathered information during its August workshop, through Internet searches and direct communication with program managers, and by reviewing recent studies examining related R&D programs (e.g., NRC, 2000c; DOE, 2000g). Summaries of a number of related R&D programs are provided in Appendix E. This analysis was necessarily limited, and the list of R&D programs in Appendix E and the discussion that follows, should be read with this caveat in mind.

A recent NRC report, *Research Needs in Subsurface Science* (NRC, 2000c), identified 18 federal R&D programs in 8 agencies that support research "closely related" to DOE's EMSP research to solve subsurface contamination problems at its facilities. Thus, just in this one area, there are numerous related programs in other federal agencies. The committee achieved similar results in its broader, admittedly limited, review of R&D programs that address environmental problems closely related to those in DOE's EQ business line. The range of issues addressed and the number of related programs in other federal agencies and abroad is illustrated by the following examples:

TABLE 3.1 Related Research Activities Sponsored by DOE's Office of Science

Research Activity	FY 00Budget (million $)	FY01 Budget Request (million $)
Natural and Accelerated Bioremediation Research Program	25.2	21.1
Cleanup Research	3.4	2.7
Waste Management	–	8.1
Heavy Element Chemistry	6.7	7.4
Chemical Energy and Chemical Engineering	9.0	10.0
Analytical Chemistry Instrumentation	4.6	5.8
Separations and Analysis	12.6	14.6
Materials Chemistry	25.8	27.6
Mechanical Behavior and Radiation Effects	16.6	16.4
Health Risks from Low Dose Exposures	18.3	11.7
Environmental and Molecular Sciences Laboratory	28.8	32.4
Geosciences	15.0	15.2
Energy Biosciences	25.0	28.0

Source: DOE 2000d.

- The Strategic Environmental Research and Development Program is the Department of Defense's counterpart to the DOE EQ R&D portfolio, and is operated in conjunction with DOE and EPA, as well as other federal agencies. The program supports, for example, R&D to develop improved approaches and processes to decrease the quantity of disposed wastes; to increase effective waste management efforts; and to decrease life-cycle, safety, and pollution impact costs.
- The Environmental Security Technology Certification Program, also in the Department of Defense, demonstrates and validates promising innovative technologies in the areas of environmental cleanup and compliance, pollution prevention, alternative waste processing technologies, and detection and remediation of unexploded ordnance.

- The U.S. Nuclear Regulatory Commission's Radiation Protection, Environmental Risk and Waste Management Branch develops, plans, and manages research programs related to the movement of radionuclides in the environment and consequent dose and health effects to the public and workers as a result of nuclear power plant operation, facility decommissioning, clean-up of contaminated sites, and disposal of radioactive waste.
- EPA's Waste Research Strategy addresses issues pertaining to the proper management of solid and hazardous wastes and the effective remediation of contaminated media. It focuses on four research areas: (1) contaminated groundwater; (2) contaminated soils and the vadose zone; (3) emissions from waste incinerators; and (4) active waste management facilities.
- EPA's National Risk Management Research Laboratory conducts research on methods to prevent and reduce risks from pollution that threatens human health and the environment. Its projects include evaluating the cost-effectiveness of methods for prevention and control of air, land, and water pollution; remediation of contaminated media; and restoration of ecosystems.
- EPA's Superfund Innovative Technology Evaluation Program focuses on the development of alternative or innovative treatment technologies.
- EM's Office of Science and Technology and EPA's Office of Solid Waste recently signed a memorandum of understanding to improve cooperation on the development of technical solutions and regulations to address environmental problems associated with mixed wastes.
- The Electric Power Research Institute operates a decommissioning technology program designed to assist utilities in minimizing the cost of decommissioning through enhanced planning, application of lessons learned by other utilities with retired plants, and use of advanced technology. Projects include development of technologies for chemical decontamination, site characterization, and concrete decontamination.
- There are a number of R&D programs in other countries, such as Britain, France, and Japan, that focus on disposal of radioactive wastes—particularly high-level radioactive waste (NRC, 2001).
- The National Institute of Health's Superfund Basic Research Program conducts research on the human health and ecological risks of hazardous substances and promotes the development of new, cost-effective environmental technologies.

In short, there are numerous U.S. government R&D programs that are closely related to R&D activities supported by the EQ business line. Areas of significant overlap include remediating contaminated groundwater and sites, reducing waste generation, and understanding the fate and transport of contaminants in the subsurface. For some of these overlapping issues, DOE is involved in cooperative efforts with other agencies, such as the Strategic Environmental Research and Development Program and the memorandum of understanding with EPA on mixed waste issues. Further, some EQ R&D objectives that are addressed by few other domestic R&D programs, such as management, treatment, and disposal of high-level waste, are being actively pursued by parallel programs in other countries. Accordingly, there are significant opportunities for EQ R&D to benefit efforts outside of DOE and even outside of the United States. Similarly, there are many opportunities to leverage the important R&D conducted outside DOE to help address DOE's EQ problems. In areas where DOE's EQ mission directly overlaps with the missions of other agencies, such as EPA and the Department of Defense, DOE should continue to look for opportunities to coordinate its R&D activities with those agencies.

Finding: A number of programs in federal agencies outside DOE and in other countries support R&D closely related to DOE's EQ mission. Specific areas where there is significant overlap include remediating contaminated media, reducing waste generation, and disposing of waste.

Recommendation: DOE should leverage the information and technologies developed in programs outside DOE and, to the extent possible, coordinate its EQ R&D with related R&D efforts in other agencies. It also should make available the information and technologies developed in the EQ R&D portfolio to industry, other federal and state agencies, and other countries.

CRITERIA TO EVALUATE THE ADEQUACY OF THE EQ R&D PORTFOLIO

An important part of the committee's task was to develop criteria that could be used to evaluate the adequacy of the EQ R&D portfolio. The committee used its descriptions of the essential functions of an effective EQ R&D portfolio from earlier in this chapter and the accompanying findings, conclusions, and recommendations to develop the following criteria to evaluate the adequacy of the portfolio:

1. **There should be no significant gaps in critical areas of science and technology that are required to address EQ goals and objectives.**
2. **The portfolio should support the accomplishment of closely related DOE and national missions.**

3. **The portfolio should include R&D to develop technical alternatives in cases where (1) existing techniques are expensive, inefficient, or pose high risks to human health or the environment; or (2) techniques under development have high technical risk.**
4. **The portfolio should produce results that could transform the understanding, need, and ability to address currently intractable problems and which could lead to breakthrough technologies.**
5. **The portfolio should leverage R&D conducted by other DOE business lines, the private sector, state and federal agencies, and other nations to address EQ goals and objectives.**
6. **The portfolio should help narrow and bridge the gap between R&D and application in the field.**
7. **The portfolio should be successful in improving performance, reducing risks to human health and the environment, decreasing cost, and advancing schedules.**
8. **There should be an appropriate balance between addressing long-term and short-term issues.**
9. **A diversity of participants from academia, national laboratories, other federal agencies, and the private sector, including students, postdoctoral associates, and other early-career researchers, should be involved in the R&D.**
10. **There should be an appropriate balance of annual new starts, extensions of promising R&D, and periodic new initiatives.**

Recommendation: DOE should use, at a minimum, these 10 criteria to evaluate the adequacy of its EQ R&D portfolio.

Most of these criteria require expert evaluations, and therefore will not provide a simple “yes” or “no” answer as to the adequacy of the portfolio (the committee discusses a process for obtaining such expert input in Chapter 4). Even so, such criteria provide a framework that decision makers in DOE, the Office of Management and Budget, and Congress could use to set performance goals and measures for the EQ R&D portfolio and to help prioritize funding decisions. The committee also chose to frame the criteria in terms of substantive goals for an effective R&D portfolio, rather than in terms of the resources required to achieve these goals. The criteria can be directly related to methods to determine appropriate investment levels, as discussed in Chapter 5.

PRINCIPAL ELEMENTS OF AN EFFECTIVE EQ R&D PORTFOLIO

An important part of the committee’s task was to provide advice to DOE on the principal elements of its EQ R&D portfolio. The committee approached this task in two ways: (1) by developing its own list of princi pal elements and (2) by developing a general methodology that DOE could use continually to identify and refine the principal elements of the portfolio. The committee's list of principal elements is presented below, and the general methodology is discussed in Chapter 4.

These principal elements were derived by analyzing the EQ business line's most pressing problems, the existing gaps in its R&D portfolio, the areas presenting the greatest opportunities for improvement, and by applying the criteria discussed in the previous section. One of the most important sources of input was the Strategic Laboratory Council's (SLC's) adequacy analysis of the portfolio (DOE, 2000g), which included a detailed analysis of the R&D gaps and opportunities in the portfolio (see Appendix C). The committee also reviewed a number of recent studies on aspects of the portfolio (see Appendix F for an annotated bibliography of the National Research Council studies that were reviewed); solicited input from experts knowledgeable about DOE's EQ mission; and convened a public workshop in August 2000 to discuss this issue and other aspects of the committee's charge (see Appendix B for workshop agenda and list of participants).

In identifying the principal elements, the committee took a high-level, long-term view of the R&D needed to address DOE's most challenging EQ problems. The committee did not define elements along existing DOE program lines, but attempted to identify crosscutting themes that apply to a number of DOE's program units. The five principal elements therefore are quite broad. To illustrate the crosscutting nature of these elements and to document the committee's basis in recommending these elements, the discussion that follows includes numerous citations to previous studies from the NRC, DOE, and other groups.[8] The topics discussed below do not constitute a comprehensive list of long-term EQ R&D needs; rather, it is intended to provide DOE with a useful starting point from which to build a more effective, long-term R&D portfolio. The committee describes how DOE could build upon this list of program priorities to achieve and maintain a more strategic EQ R&D portfolio in Chapter 4.

Recommendation: The EQ R&D portfolio should include, at minimum, the following 5 principal elements:

1. **Development and evaluation of approaches that reduce the impacts of wastes on human health and the environment through generation minimization; processing improvements, including volume reduction, stabilization, and containment; and disposal;**

[8] Although the committee has attempted to briefly synthesize the relevant message from each referenced work, readers interested in more details on any subject are encouraged to read the complete reports, where the rationales for conclusions and recommendations are described.

2. **Development of methods and techniques for cutting-edge characterization and remediation of contaminated media, including facilities;**
3. **Improvement in understanding the movement and behavior of contaminants through the environment, with an emphasis on locating and tracking the movement of contaminants in the subsurface;**
4. **Development of mechanisms for effective long-term stewardship, including improved institutional management capabilities, appropriate monitoring, and the means to implement future improvements in technology and understanding; and**
5. **Determination of the risks of DOE wastes and contaminated media to human health and the environment to improve the bases upon which regulatory and societal decisions can be made.**

Each of these principal elements is described in more detail in the sections that follow.

Development and Evaluation of Approaches that Reduce the Impacts of Wastes on Human Health and the Environment

Recent studies have identified significant long-term R&D needs in three general areas related to reducing the effects of DOE radioactive, hazardous, and mixed wastes to human health and the environment: (1) generation minimization; (2) waste processing improvements, including volume reduction, stabilization, and containment; and (3) disposal.

Generation Minimization

Minimizing the generation of DOE wastes (both new wastes and secondary wastes produced during remediation activities) is an essential element of the life-cycle approach to EQ problems emphasized throughout this report. As discussed previously, reducing the environmental consequences of future nuclear power technologies (both wastes and contaminated facilities) has been recognized as an important long-term R&D need (DOE, 2000k). Moreover, a recent NRC committee and DOE's adequacy analysis both identified the minimization of the generation of new wastes as an important and promising area for DOE R&D (NRC, 2000a; DOE, 2000g). DOE's EQ R&D portfolio does not include a specific program for waste minimization, although EM does support some R&D projects related to generation minimization during cleanup activities, and DOE has included some department-wide efforts to reduce pollution and waste in response to the Greening the Government Executive Orders (DOE, 2000g; White House, 1999).

Waste Processing Improvements

A recent NRC committee and the SLC's adequacy analysis both concluded that long-term R&D is needed to develop high-efficiency separation methods for high-level waste in order to minimize the environmental impacts of secondary wastes generated during its processing (NRC, 2000d; DOE, 2000g). Recent studies also have highlighted the importance of long-term research on new waste containment and stabilization technologies, particularly for high-level waste (NRC, 1999c, 2000c,d; DOE, 2000g). Long-term stabilization and containment is also a critical component of DOE's long-term stewardship responsibilities (NRC, 2000a; DOE, 2000g). Other reports have noted the need for long-term R&D to address the lack of final waste acceptance criteria for high-level wastes (NRC, 2000g; DOE, 2000g).

Disposal

With regard to the disposal of high-level waste and spent nuclear fuel, a December 2000 letter report from the Nuclear Waste Technical Review Board identified the conceptual design for the proposed geological repository at Yucca Mountain as one of the major technical challenges that remain with the program (NWTRB, 2000). The report stated that "DOE has not yet demonstrated a firm technical basis for its present high-temperature 'base case' repository design," and indicated that it looked "forward to the results of DOE work that is under way to evaluate the effects of alternative lower-temperature repository designs on repository and waste package performance" (NWTRB, 2000, p. 2). The SLC's adequacy analysis identified an R&D gap in collecting long-term test data to reduce uncertainty with natural and engineered barrier performance, and indicated that "R&D must continue throughout the active life of the repository to provide data for performance confirmation and to continue to make improvements" in repository and waste package design to reduce uncertainties, increase safety, or reduce life-cycle costs (DOE, 2000g, p. 27).

A panel of the Secretary of Energy's Advisory Board recently completed an evaluation of emerging non-incineration technologies for the treatment and disposal of mixed radioactive wastes. The panel concluded that viable alternatives to incineration exist and should be pursued by DOE, along with basic scientific research to develop a new generation of technologies (DOE, 2000I). DOE's adequacy analysis went even further, identifying alternatives to incineration as “the greatest gap identified among mixed waste technologies” (DOE, 2000g, p. 21).

Development of Methods and Techniques for Cutting-Edge Characterization and Remediation of Contaminated Media

Several recent NRC studies identified long-term research on the location and characterization of subsurface contaminants, and characterization of the subsurface itself, as high priorities (NRC, 2000c,d). Similarly, the SLC’s adequacy analysis found that development of improved sensors and characterization technologies for subsurface contaminants is a significant R&D gap (DOE, 2000g). Long-term R&D to develop improved characterization techniques associated with the deactivation and decommissioning of DOE facilities also was identified as a high-priority need by a recent NRC study (NRC, 2000e); that committee recommended (1) research toward identification and development of real-time, minimally invasive, and field-usable means to locate and quantify difficult contaminants significant to deactivation and decommissioning and (2) research that could lead to development of biotechnological sensors to detect contaminants of interest (NRC, 2000e).

Recent studies also have identified critical long-term R&D needs to develop technologies to remediate contaminated groundwater, soil, and facilities. A number of such studies have concluded that there are significant R&D gaps related to the remediation of subsurface contaminants (NRC, 1999b, 2000c,h; DOE, 2000g). NRC (1999b) concluded with the following summary of the status of DOE’s efforts to address its subsurface contamination problems:

> DOE faces the challenge of cleaning up massive quantities of contaminated groundwater and soil with a suite of baseline technologies that are not adequate for the job. Although recent DOE budget projections have indicated that most groundwater at DOE installations will not be cleaned up, federal law requires groundwater cleanup, and political pressure to meet the federal requirements continues. DOE will thus have to continue to invest in developing groundwater and soil remediation technologies, (p. 13)

A recent NRC study on deactivation and decommissioning problems throughout the DOE complex recommended long-term research to develop biotechnological methods to remove or remediate contaminants of interest from surfaces within porous materials; and toward creating intelligent remote systems that can adapt to a variety of tasks and be readily assembled from standardized modules (NRC, 2000e).

Improvement in Understanding the Movement and Behavior of Contaminants through the Environment

The importance of understanding contaminants' fate and transport in the environment has been duly acknowledged in several recent studies (NRC, 2000c; DOE, 2000g; NRC, 2000i). In a recent report that examined DOE's long-term stewardship responsibilities, a NRC committee came to the following conclusion:

> In some cases, the lack of sufficient pre- or post-remediation characterization of either the wastes or the environments into which they have been placed can render realistic estimation of the effectiveness of contaminant reduction measures nearly impossible. A key question for each site must be "How much characterization is sufficient to overcome this impasse?" A major concern is the adequacy of understanding of the physical and chemical properties of the environment in which contaminants reside and their transport through the environment over time. Mathematical modeling of contaminant fate and transport is an essential tool for long-term institutional management, but its track record to date at DOE sites, particularly where contaminants reside in the unsaturated, or "vadose" zone, has been mixed. This necessitates integration of a science and technology program into both site remediation planning…and the activities that follow after remediation activities cease. (NRC, 2000a, p. 6)

A recent NRC report on the Waste Isolation Pilot Plant (NRC, 2000i) emphasized the importance of establishing accurate baseline information on radioactive materials throughout a geological repository environment so that the movement and behavior of contaminants can be monitored.

R&D on the fundamental approaches and assumptions underlying conceptual modeling of the subsurface also has been identified as a long-term R&D need (NRC, 2000c). The SLC's recent adequacy analysis found that the development of improved understanding of the fate and transport of contaminants in the vadose zone is a significant R&D gap (DOE, 2000g). EM is currently developing a science and technology roadmap for contamination problems in the vadose zone, which should help DOE plan and organize future R&D efforts in this area. Research to improve the understanding of the interactions of important contaminants with materials of interest in deactivation and decommissioning projects was recommended by a recent NRC study (NRC, 2000e).

Development of Mechanisms for Effective Long-Term Stewardship

The recent report, *Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites* (NRC, 2000a), comprehensively examined the capabilities and limitations of the scientific, technical, human, and institutional systems that DOE expects to use under its long-term stewardship program. The authoring committee found that "much regarding DOE's intended reliance on long-term stewardship is at this point problematic" (NRC, 2000a, p. 3) and urged DOE to plan for site disposition and long-term stewardship much more systematically than it has to date. In particular, the committee recommended that "DOE apply five planning principles to the management of residually contaminated sites: (1) plan for uncertainty, (2) plan for fallibility, (3) develop appropriate incentive structures, (4) undertake necessary scientific, technical, and social science research and development, and (5) plan to maximize follow-through on phased, iterative, and adaptive long-term institutional management approaches" (NRC, 2000, p. 4). Among its many recommendations, the committee urged DOE to conduct scientific, technical, and social science R&D to improve its long-term institutional management capabilities. The committee emphasized that long-term R&D should address not only basic technical questions about the behavior of wastes in the diverse environments of the nation's nuclear waste sites, but also the social, institutional, and organizational aspects of long-term management systems. Similarly, a 1998 study from Resources for the Future recommended studies to evaluate institutional alternatives for assuring long-term compliance with institutional controls (Probst and McGovern, 1998).

In a January 2001 report to Congress (DOE, 2001b), DOE identified the following types of technical uncertainties that are important to the success and the assessment of the costs of the long-term stewardship program:

- the nature of the hazards remaining onsite,
- the effectiveness of monitoring,
- the maintenance of barriers and institutional controls,
- the availability of adequate technologies in the future to address residual contaminants,
- the future development of better remedial and surveillance technologies, and
- the long-term management of data.

Long-term R&D on such issues could assist DOE in addressing remaining risks to human health and the environment at closed sites (see also Sidebar 3.1). The recent SLC adequacy analysis also identified a large number of R&D gaps and opportunities in the area of long-term stewardship (DOE, 2000g, see also Appendix C).

Determination of the Risks of DOE Wastes and Contaminated Media to Human Health and the Environment

The application of a more risk-based approach to DOE's EQ problems has been a central theme of numerous recent studies (e.g., NRC, 2000f; CRESP, 1999; DOE, 2000g). For example, a recent NRC report on high-level waste (NRC, 1999d) recommended that:

> a risk analysis for the actions recommended above for both HLW calcine and SBW [sodium-bearing waste] should be conducted promptly, and should include a comparison of the risks associated with INEEL HLW calcine and SBW to the risks associated with site inventories of other radioactive wastes. A sufficiently rigorous analysis should be performed to establish the current risks and to assess the changes in risk due to treatment options, (p. xi)

The Peer Review Committee of the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) recently examined the use of risk analysis within EM, and recommended that DOE establish a sound process for developing a risk evaluation methodology that could meet EM's short-term and long-term challenges (CRESP, 1999). CRESP also identified a number of gaps in the knowledge and methods needed to develop such a methodology. SLC's recent adequacy analysis agreed with the needs described in the CRESP report and also identified the need for improved methods for communicating risks to stakeholders as a significant R&D gap in the EQ R&D portfolio (DOE, 2000g).

In summary, what is needed are more accurate, comprehensive, and transparent approaches to assessing and communicating the risks of DOE wastes and contaminated media to human health and the environment so that DOE can make more informed decisions that are accepted by stakeholders. The committee believes that the role for EQ should be to support R&D projects that directly address an EQ problem, such as the relative risks of various treatment options for high-level waste or issues associated with the relative risks and public perceptions of disposing of wastes in a geologic repository. This R&D should build upon and leverage other relevant research, such as general research on risk by EPA and other agencies and the Office of Science's research program on health risks from low-dose exposures.

EXTENDING THE EQ R&D PORTFOLIO BEYOND DOE

One of the questions that DOE asked this committee to address was whether the EQ R&D portfolio should address environmental problems outside DOE that are related to EQ strategic goals. To address this question, the committee undertook a comparative analysis of related R&D efforts outside DOE, as described earlier. The committee answers this question with a qualified "yes." The committee believes it is appropriate for the EQ R&D portfolio to address environmental problems outside DOE, provided that such R&D is directly related to DOE's EQ mission. Earlier in this chapter, the committee concluded that DOE's EQ R&D should be closely coordinated and integrated with relevant parts of DOE's other business lines. Further, it concluded that DOE should leverage the information and technologies developed in programs outside DOE and should make available the information and technologies developed in the EQ R&D portfolio to industry, other federal and state agencies, and other countries.

The committee found no basis to conclude that the EQ R&D portfolio should encompass environmental problems beyond DOE's jurisdiction that are unrelated to DOE's EQ mission. To the contrary, the committee concludes that DOE's current EQ R&D portfolio does not address important long-term EQ problems that are already the responsibility of the EQ business line. There may very well be cases in which spending limited R&D resources on problems outside DOE's EQ mission is appropriate, but deciding when this would be appropriate is less a technical question than a matter of general policy.

Finding: DOE's current EQ R&D portfolio does not adequately address important long-term problems that are already the responsibility of the EQ business line.

Conclusion: It is appropriate for the EQ R&D portfolio to address environmental problems outside DOE if such R&D is directly related to DOE's EQ mission. At this time, however, the EQ R&D portfolio should not address environmental problems beyond DOE's jurisdiction that are unrelated to the EQ mission.

MEETING DOE'S LONG-TERM EQ R&D NEEDS

This chapter has discussed the responsibility of DOE for a broad array of R&D activities that can have a dramatic impact not only on DOE's EQ mission but also on its Energy Resources, Science, and National Nuclear Security missions. The EQ responsibilities of DOE are profound, broad, and enduring and they encompass a broad range of issues ranging from the dismantlement of nuclear weapons, with its attendant nuclear materials management, national security, and disposal issues, to the environmental impacts associated with nuclear power and other energy sources. If properly scoped and managed, the EQ R&D portfolio should provide an improved technical foundation for addressing DOE's EQ problems, while setting the highest standards for future environmental stewardship.

The committee pointed out in Chapter 2 that inconsistencies and changes in descriptions of DOE's EQ responsibilities over time may have interfered with developing broad-based support for its EQ R&D efforts. Earlier in this chapter, the committee recommended that DOE establish a long-term, strategic vision for its EQ R&D portfolio. The process of formulating such a vision creates an opportunity to establish clear and consistent objectives that not only provide a baseline for determining an adequate R&D portfolio but that could make it clear that DOE's EQ mission is central to ongoing and future programs throughout the department. One critical goal, in particular, should be to move away from the current "going out of business within the next decade" approach to EQ R&D.

4

ACHIEVING AND MAINTAINING THE LONG-TERM VISION FOR ENVIRONMENTAL QUALITY RESEARCH AND DEVELOPMENT

Chapter 3 described a vision for a different Environmental Quality (EQ) research and development (R&D) portfolio that would have a strong, if not dominant, long-term component. To move towards this vision, the Department of Energy (DOE) will need to redesign and rebalance its EQ R&D portfolio in substantial ways to better focus on its long-term EQ problems.[1] This chapter describes a new portfolio management process that could help achieve these goals.

To be effective, R&D portfolio management must operate within an effective management system, which includes identifying the decision maker (or decision-making group) who will make the hard choices of prioritization, resource allocation, and balance. Portfolio management systems for federal R&D programs also commonly seek out and use input from broadly qualified individuals in generating a comprehensive set of R&D needs and project possibilities. In general, the generation and selection of R&D projects should have inputs from qualified persons both inside and outside the program. This chapter discusses several institutional mechanisms that DOE could use to improve the management of its EQ R&D portfolio, including ways to generate and incorporate such input.

For the most part DOE can implement the recommended new portfolio management process through an evolutionary approach (i.e., by modifying and supplementing existing management processes). The committee believes this is possible because DOE is already using portfolio management techniques (DOE, 2000b,g), and external reviews have found that management based on these techniques is yielding positive results but could be greatly improved (DOE, 2000h). Such an approach avoids disruptive reorganizations and maintains management focus on the goal (i.e., realizing the new R&D vision).

[1] As noted previously, the term “EQ problems” refers to the set of technical problems that collectively make up the EQ challenges described in Chapter 2. This is a useful concept in planning an R&D portfolio, because the challenges are very broad, and must be broken down into manageable parts to be addressed by R&D.

R&D PORTFOLIO MANAGEMENT PROCESS

The primary objective of portfolio management is to ensure that an R&D portfolio is aligned, valuable, and balanced. "Alignment" is intended to ensure that the portfolio supports the strategic objectives and strategic direction of the parent organization (i.e., DOE's EQ mission and objectives). "Value" measures that support in quantifiable terms, such as net social benefit or utility. "Balance" examines whether the portfolio covers the full scope of objectives and approaches or is too narrowly focused on certain categories of R&D, time frames, or topics.

In practice, these three objectives are often treated in sequence. An alignment process typically generates a list of R&D "possibilities" to be considered for funding by a decision maker. The adequacy analysis that identified the extensive list of R&D gaps and opportunities (see Appendix C) was essentially an alignment exercise. A valuation process is one means of prioritizing the list of R&D possibilities so that scarce resources can be applied to deliver the maximum benefit. The Work Package Ranking System (WPRS) that is currently used to select R&D work packages within the Office of Environmental Management (EM) has many similarities to a value-based prioritization system.[2] Balancing a portfolio is a formal process for examining and considering how resources are distributed across critical dimensions and is applied after valuation to offset any imbalances that are inconsistent with overall program objectives. Examples of the types of displays that can be used to evaluate balance include diagrams displaying funding distribution across R&D maturity (Figure 2–6 of DOE, 2000b) and the levels of involvement of universities, national laboratories, contractors, and industries at various stages of R&D maturity (Figure 2–7 of DOE, 2000b). In the following sections, the committee discusses DOE's EQ R&D portfolio management processes in terms of the objectives of alignment, value, and balance.

Alignment: Generating Improved Project Ideas

Each of the DOE organizations that support EQ R&D has its own process for generating R&D project ideas. These planning processes are designed primarily to gather site and repository needs, which tend to be focused on short-term problems, and to turn these into R&D projects. For example, the participants who determine EM's site needs typically are DOE employees and contractors who are closely involved with the site problems and issues (NRC, 1999a), with some periodic input from the broader

[2] DOE does not have a single evaluation method for prioritizing R&D activities across the entire EQ R&D portfolio. Each organization that supports EQ R&D activities has its own process for prioritizing and selecting R&D projects.

technical community, such as from the Environmental Management Advisory Board (EMAB, see Sidebar 4.1). The R&D activities supported by the Office of Civilian Radioactive Waste Management (RW) are identified primarily by DOE staff and contractors at the Yucca Mountain Site, although

SIDEBAR 4.1 ENVIRONMENTAL MANAGEMENT ADVISORY BOARD

The Environmental Management Advisory Board (EMAB) was created to provide independent, expert advice, information, and recommendations to the Assistant Secretary of Environmental Management (EM) on issues related to environmental restoration and waste management. Members of EMAB include representatives from state and local governments, tribal nations, environmental groups, labor organizations, private industry, and scientific and technical communities.

EMAB is organized into standing committees, ad hoc committees, and working groups. Three of EMAB's six active standing committees, and one of its ad hoc committees are particularly relevant to this study: The Technology Development and Transfer Committee, the Science Committee, the Long-Term Stewardship Committee, and the Ad Hoc Committee on Technology and Innovation. The missions of these four committees are described below.

The mission of the **Technology Development and Transfer Committee** is to develop implementable recommendations for the Assistant Secretary of EM that can facilitate the development and use of environmental technologies capable of addressing DOE's environmental problems.

The mission of the **Science Committee** is to examine the quality of science in the EM program on behalf of the Assistant Secretary with special emphasis on areas where new science and technology are needed, analyze scientific and technical problems and issues as they arise, and work toward ways to expedite and more efficiently reduce DOE's inherited legacy of environmental cleanup and waste treatment and disposal.

The mission of the **Long-Term Stewardship Committee** is to provide advice and recommendations to the Assistant Secretary on actions EM should take to prepare for and make the transition from its current active programs to long-term stewardship of waste material and property.

The charge for the **Ad Hoc Committee on Science and Innovation** is to examine the linkage between DOE environmental science programs and the long-term stewardship requirements of EM and to recommend how resources and processes could be improved to enable science to be better applied to solving the long-term problems.

Source: Environmental Management Advisory Board web site (http://www.em.doe.gov/emab/)

the Nuclear Waste Technical Review Board also plays a role in identifying science and technology needs for the RW program (see Sidebar 4.2). The Office of Nuclear Energy, Science and Technology (NE) relies on its Nuclear Energy Research Advisory Committee to generate long-term R&D needs (see Sidebar 4.3), although these needs are primarily directed towards nuclear power R&D[3] (and hence DOE's Energy Resources R&D portfolio), because that is NE's overall programmatic focus. In addition, as discussed in Chapter 2, both EM and RW are driven by short-term milestones and deadlines. The short-term drivers and the limited set of participants work together to limit the development of the broad R&D portfolio that was envisioned in Chapter 3.

SIDEBAR 4.2 NUCLEAR WASTE TECHNICAL REVIEW BOARD

Congress created the Nuclear Waste Technical Review Board in 1987 to review DOE's scientific and technical activities pertaining to the management and disposal of the nation's commercial spent nuclear fuel and high-level radioactive waste. These activities include characterizing Yucca Mountain, Nevada, as a potential repository site and packaging and transporting commercial spent nuclear fuel and defense high-level waste.

The board is an independent agency of the U.S. Government whose sole purpose is to provide independent and expert review of the DOE program. The board is composed of 11 members who are experts in science or engineering (including environmental and social sciences) who are selected on the basis of distinguished service. The National Academy of Sciences recommends candidates and the President makes the appointments.

The board has the following primary areas of responsibility:

- makes scientific and technical recommendations to DOE to ensure a technically defensible site-suitability decision and license application;
- advises DOE on the organization and integration of scientific and technical work pertinent to the Yucca Mountain Site; and
- provides an ongoing forum that fosters discussion and understanding among DOE and its contractors of the complex scientific and technical issues facing the program.

Source: NWTRB, 1999.

The recent adequacy analysis of the EQ R&D portfolio conducted by DOE's Strategic Laboratory Council (SLC) was DOE's first attempt to generate R&D project ideas for the entire EQ R&D portfolio (see Appendix C

[3] Although the strategic plan included sections on isotopes, space applications, and basic materials research.

). In part because planning has focused primarily on short-term problems, the SLC's adequacy analysis found that the present EQ R&D portfolio does not include a longer-term vision and "strategic elements" and has significant gaps and opportunities (DOE, 2000g). How do these statements fit with the fact that DOE already supports a significant amount of long-term research? The answer lies in the term "strategic," which refers to a plan or method for achieving a goal, including the purposeful allocation of resources. The Office of Science (SC) supports nearly $3 billion in long-term, basic research and scientific user facilities primarily to advance science—not to solve EQ problems (or the problems addressed by DOE's other business lines). Thus, SC research is not "strategically" oriented to EQ purposes, although some of it may provide information useful to the EQ mission. EM also supports problem-oriented, longer-term research in its Environmental Management

SIDEBAR 4.3 NUCLEAR ENERGY RESEARCH ADVISORY COMMITTEE

The Nuclear Energy Research Advisory Committee was established in 1998 to provide independent advice to DOE and its Office of Nuclear Energy, Science and Technology (NE) on complex science and technical issues that arise in the planning, management, and implementation of DOE's nuclear energy program. The advisory committee periodically reviews the elements of the NE program and based on these reviews provides advice and recommendations on long-range plans, priorities, and strategies to address the scientific and engineering aspects of the R&D efforts. In addition, the committee provides advice on national policy and scientific aspects of nuclear energy research issues as requested by the Secretary of Energy or the Director of NE. The committee includes representatives from universities, industry, and national laboratories and has the following primary areas of responsibility:

- conducts periodic reviews of elements of the nuclear energy R&D program within NE and makes recommendations based thereon.
- advises on long-range plans, priorities, and strategies to address more effectively the scientific aspects of nuclear energy R&D and stakeholder aspects of the services of NE.
- advises on appropriate levels of funding to develop those plans, priorities, and strategies and to help maintain appropriate balance between elements of the program.
- advises on national policy and scientific aspects of nuclear energy research issues of concern to the DOE as requested by the Secretary or the Director of NE.

Source: Nuclear Energy Research Advisory Committee web site (http://www.ne.doe.gov/nerac/neracoverview1a.html)

Science Program (EMSP). Although all the projects EMSP supports are problem-oriented, they do not, nor were they intended to, comprise a coherent, strategic effort at solving particular EQ problems (see http://emsp.em.doe.gov/). One major reason is that the EMSP budget is small compared to the panoply of scientific problems covered by the program's scope, so that only relatively small, isolated research projects of limited duration are supported.

In summary, the present bias of the EQ R&D portfolio toward short-term R&D (DOE, 2000b,g, h) is to be expected given:

1. the way that EM and RW (and to a lesser extent, NE) presently identify R&D needs,
2. EM's goal of closing the maximum number of sites (mostly smaller sites) by 2006,
3. RW's short-term focus on technical issues associated with site recommendation and licensing,
4. the strong emphasis that EM, especially, has placed on getting technologies deployed, and
5. declining EQ R&D budgets.

Finding: The existing processes for generating EQ R&D needs are driven largely by DOE's regulatory mandates, contractor incentives, and short-term goals.

Conclusion: The existing R&D planning processes are unlikely to generate the full scope of strategic R&D needed to address DOE's most challenging, long-term EQ problems.

Recommendation: DOE should establish a new mechanism within its portfolio management process whose purpose is to develop a more strategic EQ R&D portfolio. The new process should supplement and operate in parallel with existing site-driven processes.

The primary purpose of the recommended new process, which the committee terms the "Strategic Portfolio Review," would be to identify the gaps and opportunities in the existing portfolio that, when adequately addressed, would encompass the entire spectrum of EQ problems. This Strategic Portfolio Review would be similar to the SLC's adequacy analysis, except that a broader group of experts would participate in the analysis and more explicit criteria that emphasize long-term R&D would be used. Institutionalizing this process is consistent with recent recommendations made by EMAB (DOE, 2000h).

Adequacy would be assessed and gaps and opportunities identified by the judgment of a group of knowledgeable, experienced, and collectively (i.e., as a group) unbiased experts, preferably from both within and outside the DOE community (how to constitute such a group of experts is discussed more fully in the section "Broadening and Deepening the EQ R&D Portfolio"). Gaps and opportunities would be identified using the criteria recommended in Chapter 3 (primarily criteria 1 through 7). The broader scope of the Strategic Portfolio Review would generate a separate, broader, and deeper source of R&D needs on which to solicit, evaluate, and potentially fund additional projects, with emphasis on those that address the highest-priority EQ problems. An example is long-term stewardship, which raises issues involving policies and time scales beyond those now considered in the present R&D portfolio (NRC, 2000a). This requires that the Strategic Portfolio Review focus on the enduring, most challenging problems needing solution, and not on current activities—whether in remediation, waste disposal, or waste management. The expanded set of EQ R&D projects to be considered for funding would consist of projects emerging from the traditional needs processes as well as the new Strategic Portfolio Review.

Value: Measuring the Magnitude of the Benefit

The gaps and opportunities identified by the Strategic Portfolio Review plus the existing R&D needs processes probably will generate far more demand for R&D activities than can be addressed by current or even greatly expanded resources. Therefore, potential R&D activities will need to be evaluated and prioritized. The goal of valuation is to measure the magnitude of the benefit expected as a result of successful R&D so that scarce resources can be applied to deliver the maximum benefit. Value measures this benefit in quantifiable terms, such as net social benefit or utility. Bjornstadt et al. (2000) have made a strong case for a value-based resource allocation approach for EQ R&D. They suggest risk reduction, cost reduction, and meeting unmet cleanup needs as three components of the potential value of cleanup R&D. They illustrate this approach using a formal non-linear programming model of the Oak Ridge National Laboratory cleanup effort developed for risk analysis (Bjornstadt et al., 1998). Another application of the approach (though used to prioritize relatively short-term R&D needs) is Kaiser-Hill's work at Rocky Flats to identify, prioritize, and mitigate risks to closure project schedule and cost using what was described as an economic optimization approach to decision-making (Kaiser-Hill, 2000). Both of these applications stress the importance of being able to quantify and evaluate risk and uncertainty reduction using "value-of-information" techniques, because the result of R&D is frequently better information as well as new technology. The value-of-information metric for allocating both basic and applied research resources also has been recommended by Fischhoff (2000).

Jenni et al. (1995) discussed an extensive application of a decision support system called the Environmental Restoration Priority System (ERPS). At the heart of ERPS was a multi-attribute utility model, formally elicited from DOE managers, that accounted for six types of benefit:

1. reduced health risks,
2. reduced environmental impacts,
3. reduced adverse socio-economic impacts,
4. compliance with applicable laws and regulatory requirements,
5. reduced ultimate cost of clean-up, and
6. reduced uncertainties relating to risks and costs.

Jenni et al. (1995) used a decision-analytic, value-of-information calculation to quantify the benefits of reducing uncertainty, much as the examples discussed above. Benefits 1–4 had explicit dollar value tradeoffs expressed, such as $200 million to eliminate a 1/10 per year risk of death to the maximally exposed individual, allowing the overall benefit to be translated to equivalent dollars. There were seven full-scale applications of the system between 1988 and 1991, which were "praised in technical review, but strongly criticized by stakeholders external to DOE" (Jenni et al., 1995).[4] A conclusion is that rational value-based systems do work and can in fact deliver most of the promised benefits in use in the DOE EQ environment. It is extremely difficult, however, to convince stakeholders and sites that local interests and site-specific needs can be served by a system explicitly designed with national objectives in mind.

DOE does not have a method for prioritizing and selecting R&D activities across the entire EQ business line, as each DOE organization that supports EQ R&D activities has its own process. The current process used to prioritize EM's R&D needs (OST's WPRS) resembles ERPS as a multi-attribute scoring system. RW uses a "focused approach" that funds the R&D work required to allow submittal of the site recommendation report and, if the site is selected, the license application to the Nuclear Regulatory Commission. NE considers potential life-cycle cost savings, potential reduction in environmental safety, and health risks, technical viability, and regulatory requirements to prioritize its R&D investments.

Because EM supports over 80 percent of the R&D activities within the EQ R&D portfolio, and because the WPRS is a fairly well documented, formalized process, the committee discusses it at some length in the following paragraphs. The purpose of this discussion is to explain why the WPRS currently emphasizes short-term R&D needs, and to suggest ways that the WPRS could be modified to be useful in identifying long-term R&D needs. The ranking system is based on five criteria:

[4] It should be recognized that the sites also have reasons for parochialism, as discussed in Chapter 2.

1. project baseline summary "value" (i.e., a measure of the total life-cycle costs of the baseline technologies to be replaced by a given work package, which is intended to reward those work packages that address high-cost projects and that can be employed at more than one location);
2. future technology deployments (i.e., the number of times the technologies within a work package are expected to be deployed);
3. response to site science and technology needs (i.e., the number of site-identified priority needs addressed by the work package);
4. addressing technical risk (i.e., a measure of the baseline technology's technical risk); and
5. technology cost savings (i.e., a measure of the potential ability of the work package to achieve cost savings compared to baseline technologies).

The WPRS offers a number of major benefits relative to earlier methods used in EM, including being based on end-user life-cycle planning data, better understanding of work package benefits, and direct alignment with EM's four corporate performance measures.[5] The ranking system has been favorably reviewed by EMAB (DOE, 1999b) and appears to do a good job of concentrating on site needs and deployable technologies.

There are, however, several features of WPRS that limit its usefulness as a valuation tool for the types of R&D that are under-represented in the EQ portfolio (DOE, 2000g). Because EM's four corporate performance measures are understandably oriented toward near-term accomplishments, the ranking system inherits that near-term focus. In particular it is directly tied to needs articulated by the sites, who by their nature have a more operational, shorter-term focus; one would not expect them to focus on needs beyond 2006. Also, the primary incentive for most sites is to meet their legal and contractual obligations, so a new technology that offers significant cost reduction but might delay the program is typically unwelcome.

There are additional reasons why the WPRS is currently not well suited for evaluating the R&D oriented at strategic R&D. The five criteria included in the ranking system are not as reflective of society's priorities as they are of EM management's performance measures. While this is by design, the six criteria used in the ERPS, for example, are a better reflection of national needs. Other better alternatives would be to use the seven EQ objectives listed in the R&D Portfolio Overview (DOE, 2000i) or the five refined EQ objectives used in the adequacy analysis (DOE, 2000g), including stewardship. A guiding principle for the design of an improved evaluation system should be that it could apply equally well to all areas of the EQ portfolio, not just to EM.

[5] (1) number of new technology deployments, (2) life-cycle cost reduction from use of science and technology, (3) number of high-priority needs that are met, and (4) reduction in critical pathway milestones and waste stream technical risk (DOE, 2000n).

In addition, there appears to be some redundancy (or lack of independence) among the five WPRS criteria. For example, "site technology needs addressed" also is reflected in number of deployments, technical risks addressed, and technology cost savings. Having it as an additional criterion could lead to double counting. In addition, working on "high value" project baseline summary elements is not an end in itself, unless it leads to large improvements in the cost savings or technical risk categories. As an example, a diffuse work package that addressed many maximum-value project baseline summary elements but had trivial impact on technical risk or cost savings could have the same score as a tightly focused project that had maximum impact on reducing technical risk in one very low cost (but critical) project baseline summary element, although only the latter would produce any benefit. Although projects with no real potential benefits are unlikely to be proposed, it would be better for the scoring system to rate them very low. Finally, "high-value" project baseline summary elements are actually based on cost, not value, so this criteria is questionable as defined. For these reasons, the use of these five criteria in an additive multi-attribute utility model is open to question.

It is unclear how the probability of technical success of the R&D projects in the work packages enters into the WPRS evaluation method. Typical R&D evaluation methods (NRC, 1999a) involve benefit, cost, and probability of technical success in the prioritization process. It could be that this is intended to be captured by a number of deployments, but that is not the same. It is also unclear how the value of time (e.g., discounting of future cost and benefits) is dealt with in the WPRS process. Finally, the value of information, which was a key feature of several of the other systems cited, is not evident in the WPRS.

In summary, the WPRS as currently implemented is EM-specific and is not well suited to evaluating long-term R&D. Something more like the examples of Bjornstad et al. (2000) and Jenni et al. (1995) is needed for more strategic R&D. Although separate evaluation methods may be needed in the short term, it may be possible for the present WPRS to evolve to one that addresses the concerns outlined above, that works for all areas of the EQ portfolio, and that is equally robust for both long- and short-term R&D, using many of the same data but with a modified algorithm along the lines of those discussed above. It would be highly desirable for the probability of technical success of work packages (or projects within work packages) to be made explicit, the treatment of time preference clarified, and the value of reducing uncertainty captured by the improved system. It also might be valuable for EQ to learn how industry treats probability of technical success, especially industries where technical risk is high (e.g., pharmaceuticals). Finally, as discussed in Jenni et al. (1995), to be effective such a methodology must be designed and applied openly and objectively so that all stakeholders can provide comments and understand what is being done.

Finding: The current Work Package Ranking System is heavily biased toward activities that are site generated and connected to the present baseline plans. Moreover, it is by design EM specific and therefore does not apply to other parts of the EQ R&D portfolio.

Conclusion: The current Work Package Ranking System is unlikely to be effective in prioritizing R&D activities designed to address the long-term strategic gaps and opportunities identified in the Strategic Portfolio Review discussed above, especially those not within EM.

Recommendation: DOE should develop and implement an evaluation method to address more strategic R&D for the entire EQ R&D portfolio. In the short term, it could be entirely separate from the EM's Work Package Ranking System, but in the longer term a new approach is needed that works for both site-driven and strategy-driven activities and is applied within all areas (i.e., EM, RW, NE) of the EQ R&D portfolio.

Several good models for such a system that have been applied to elements of the DOE EQ portfolio but that are not EM specific have been discussed above.

Balance: Ensuring Adequate Attention to Diverse Objectives

A common experience in life is that the urgent overwhelms the important. It is typical in business R&D organizations that, without strategic guidance, requests for short-term product and process improvements can exhaust the available resources. The results of SLC's adequacy analysis indicate that this is likely true for EQ R&D. Balancing can offset such forces by examining how resources are distributed across various critical dimensions, such as how R&D is distributed across the strategic objectives of the parent organization, across time frames, across risk versus return, or across R&D stages.[6] Balance is also important when the potential value of one objective is so large that projects addressing it tend to dominate projects addressing the other objectives, as might be the case for efforts to reduce the cost of some of DOE's most expensive cleanup problems. The diversity of these considerations demands that DOE seek and use the breadth of advice described in the next section.

One of the most common balance metrics in business is the relation of technical risk (or the probability of technical success) to return (i.e., value). Allowing DOE to track technical risk and value would be another benefit of

[6] For the EM portion of the EQ portfolio, how R&D is distributed across focus areas and sites also may be useful to DOE decision makers.

making probability of technical success an explicit part of the evaluation process.

Three of the 10 adequacy criteria (8–10) developed in Chapter 3 pertain to elements of portfolio balance. The most fundamental balance issue is the proportion of the budget that should be allocated to strategic R&D as opposed to R&D driven by short-term needs. There is no simple answer to this question. For example, the appropriate proportion of strategic R&D would be quite different in DOE's Energy Resources R&D portfolio, where nearly all commercialization and deployment is done in the private sector, than in the EQ R&D portfolio, where deployment and application are mostly internal to DOE and its contractors. A number of recent analyses have concluded, however, that more strategic R&D is needed to adequately address DOE's EQ objectives (DOE, 2000g,h). In addition, the SLC's adequacy analysis (DOE, 2000g) examined the funding distribution across the technology maturity spectrum and concluded that it is unbalanced. The committee discusses methods for evaluating EQ R&D funding balance in Chapter 5.

INSTITUTIONAL MECHANISMS

This section discusses implementation of the recommendations made above and offers additional recommendations related to institutional mechanisms that could be used to make the EQ R&D portfolio more effective in addressing long-term problems, including the personnel needed to carry out the Strategic Portfolio Review and a new approach to long-term EQ R&D that could be added to existing programs.

Broadening and Deepening the EQ R&D Portfolio

Several reviews of the EQ R&D portfolio have concluded that the portfolio is too narrowly focused on short-term problems and needs a broader perspective to address the most challenging EQ problems and to limit contamination and materials management problems in ongoing and future DOE operations. For the portfolio to adequately address DOE's most challenging EQ problems, the agency must gather input for the Strategic Portfolio Review from a much wider range of people than it customarily involves in its program management (see for example: DOE, 2000h; NRC, 1998, 1999a). To achieve this, several kinds of individuals are needed. Although individual experts are almost by definition narrow in scope, a well-chosen group of informed individuals working together can achieve a very broad perspective. The following categories illustrate by example the range of knowledge individuals can bring so that collectively they match the breadth of the EQ problems to be addressed:

- practical, problem-oriented, and technically trained experts with relevant experience (e.g., from a relevant industry or a foreign, federal, or state agency with a similar mission);
- applied researchers in relevant technologies (e.g., radiation hardening of sensors);
- applied researchers in generically important technologies (e.g., robotics);
- "basic" researchers in relevant areas (e.g., actinide chemistry);
- "basic" researchers in generically important sciences (e.g., physical chemistry);
- individuals possessed with a broad, long-term perspective of where technology, science, and/or environmental problems and policies are trending but who are from outside the DOE family of employees, national laboratories, contractors, and others whose interests might appear to represent substantial conflicts of interest; and
- technically qualified individuals representing nongovernmental organizations and other stakeholders.

Participation must be broadened carefully to ensure the success of the strategic review process. That is, the composition of the group should balance the need for a diversity of expertise with the need for an efficient process. The intent is to select a group of individuals who collectively are not predisposed in favor of the existing portfolio or any particular approach to solving a specific EQ problem (that is, individual biases in the group will be balanced). Consideration should be given to experts from other countries who have the needed expertise because these individuals can bring valuable perspectives to the review and are less likely to have a stake in the outcome. Qualified individuals from outside the program bring a broader perspective and often can look "outside the box" for new approaches. Of course strong input also is needed from DOE staff who have responsibility for accomplishing the EQ mission and special familiarity with the difficulties they face, and who must have the final word if they are to be accountable.

The purpose of the strategic review would be to attain the broader input and perspectives that seem lacking (DOE, 2000h). The group should be able to identify the full scope of R&D needed to solve EQ problems and to give rough priority rankings. DOE might chose to experiment with organizational approaches to find the best way to gather and use the information such a group can provide. For example, the group could be established as a new, ongoing EQ R&D advisory board. Another possible approach would be create this group largely from members of EMAB, the Nuclear Waste Technical Review Board, and the Nuclear Energy Research Advisory Committee (see Sidebars 4.1, 4.2, 4.3). This group would differ from EMAB, the Nuclear Waste Technical Review Board, and the Nuclear Energy Research Advisory Committee in that it would focus on the EQ R&D portfolio, have continuity to see how its recommendations were carried out, and be much more integrated Into and a part of the regular EQ R&D management process. Such a board would report to the manager of the EQ R&D portfolio, and if such a manager does not exist, to the line managers of its components (e.g., the Assistant Secretary for EM, the Director of RW, the Director of NE). It would meet at least annually as needed to develop a strong R&D portfolio.

Conclusion: An independent advisory group representing a broad spectrum of expertise and experience is necessary to assure a sustained, high-quality EQ R&D portfolio.

Recommendation: DOE should establish an independent planning and review board specifically focused on the EQ R&D portfolio, with membership composed of leaders in the scientific and technical community, including experts from industry, academia, national laboratories, and affected communities. The purpose of this board would be to recommend to DOE management and justify in terms of program and mission a world-class R&D portfolio with the breadth and depth to address EQ problems.

Technical Qualifications of Staff

The EQ R&D portfolio represents a highly technical activity, and must be managed by a staff with strong technical qualifications (DOE, 2001 a). The portfolio management techniques and the independent advisory board recommended above do not reduce the need for strong in-house technical management, because DOE staff still must make the final decisions. It takes considerable technical insight to identify a practical problem in the field and then determine whether current technology can resolve it, and if not, to translate the problem into researchable questions and eventually into R&D projects leading to understandings or technologies to mitigate the problem. EQ R&D managers must make researchers aware of how their work could lead to solutions to critical problems and convince them to pursue such useful results. Conversely, similar insight is needed when examining a proposal for fundamental research to visualize its application to practical problems—and to know whether and how it should be funded. Finally, EQ R&D managers must work with operators in the field to implement R&D results. Thus, EQ R&D managers need the technical depth and breadth to span the conceptual range from the field to the lab and back. A DOE staff with such depth and breadth would be able to take advantage of technical advice from outside groups as recommended above.

Individuals with such talents are rare, but two approaches can deal with this problem. First, management can partially compensate for the unavoidable limitations of individuals by bringing a broad range of views into management processes. Second, because universities generally do not train individuals with such a comprehensive grasp of problems and solutions, DOE might have to adopt institutional approaches to develop them. A recent EMAB report on the role and status of basic science in EM recommended that EM address this issue by developing "operational procedures" for OST staff positions similar to those used by ERA and that OST establish requirements for those positions that reflect their scientific and technical nature (DOE, 2001 a). The new approach to addressing DOE's long-term EQ problems described below also could help develop such people.

An Approach to Addressing DOE's Most Challenging, Long-Term EQ Problems

Chapter 3 described a set of criteria that could be used to evaluate the adequacy of DOE's EQ R&D portfolio. These same criteria can be used to help design a new approach to EQ R&D that could improve its effectiveness in addressing these long-term currently intractable problems, and which would supplement existing R&D programs. For example, the approach should:

- Address critical R&D gaps needed to address EQ goals (and when appropriate, to support the accomplishment of related DOE and national missions).
- Encourage the development of alternatives to technologies that are costly, inefficient, or pose high technical risk.
- Produce results that could transform the understanding, need, and abilities to address currently intractable problems, thus enabling breakthrough technologies.
- Lead to improved performance, reduced human health or environmental risks, decreased cost, and advanced schedules.
- Help leverage other R&D, such as the Environmental Management Science Program.
- Help to narrow and bridge the gap between R&D and application.
- Improve the balance of long- versus short-term research.
- Involve a diversity of participants from academia, national laboratories, other federal agencies, and the private sector, including students, postdoctoral associates, and other early-career researchers.
- Include a balance of annual new starts, extensions of promising R&D, and periodic new initiatives.

The committee believes that in order to meet these criteria, a significant fraction of R&D should be conducted in organizationally separate units to help maintain a focus on long-term results. Each of these units would be strongly coupled to an important, currently intractable EQ problem and evaluated according to progress on solving the problem, but not strongly coupled to short-term program needs. Based on these general criteria and considerations, the committee arrived at the following finding and recommendation. The committee then describes some of the characteristics of the recommended approach.

Finding: Given the long-term nature of many of DOE's EQ problems, there is a need to develop sustained support for R&D activities to solve such problems.

Recommendation: DOE should implement a new approach to provide longer-term funding for organizationally separate, integrated, and coordinated R&D activities (i.e., R&D centers) designed to solve well-defined, high-priority EQ problems.

The most important element of the recommended approach is that each R&D center[7] should focus on providing longer-term support for solving a particular long-term EQ problem, specifically countering the "going out of business within the next decade" philosophy that has permeated some views of the EQ portfolio (see discussion in Chapter 2). Here it is appropriate to differentiate and clarify what is meant by the phrase "a particular long-term EQ problem" with respect to other concepts, such as "EQ challenge" and "focus area." The committee's term "EQ challenge" (see Chapter 2) refers to the broad challenges facing DOE in its EQ mission area. The management of EM has organized its R&D effort to address some of these challenges into "focus areas" and "crosscutting programs." All of these are very different from what the committee means by a "problem." First, they are much broader and more general. Second, they do not refer to an integrated, coherent effort to solve a problem, but to collections of R&D efforts. Third, focus areas and crosscutting programs sometimes mean problems, but usually mean R&D activities—an unfortunate confusion. The universe of problems that might be assigned to R&D centers, taken together, overlaps with the long-term component of all the EQ challenges and of all the focus areas and crosscutting programs. What "problem" means here is an issue, a hindrance to progress, that is appropriate to be

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[7] The committee refers to the organizations carrying out the integrated and coordinated R&D efforts as R&D centers to indicate that the whole of each is greater than the sum of its parts, i.e., that integration and coordination to focus on a central, often multidisciplinary problem leads to synergy and a holistic solution. This synergy could be achieved through a variety of organizational approaches. For example, the centers could have a virtual aspect, using technology to involve experts at various locations. Thus one sort of balance to be struck is that between the benefits of daily face-to-face collaboration and achievement of critical mass in that sense versus the achievement of a different sort of critical mass by involving many geographically dispersed experts. A center could not be completely virtual, however. For example, there would have to be a locus of coherence, accountability, and problem ownership.

addressed by a single integrated, coordinated, focused R&D effort of the scale that can be supported realistically.

DOE could initiate the new approach by identifying a few well-defined high-priority problems and releasing a set of competitive requests for proposals calling for integrated and coordinated R&D activities to solve each problem. As discussed above, each problem would be a manageable part of the larger EQ challenges of Chapter 2 (i.e., it would represent a barrier to program progress), not just a scientific question. The problems to be addressed could be based on (i.e., perhaps a subset of) the gaps and opportunities identified by the Strategic Portfolio Review. At its core each problem would have at least one unanswered scientific (including social science) or technical question (i.e., this is why R&D is needed) and the centers would pursue these questions in their problem context and in consultation with users, not as pure technical questions. Assigning an R&D center a real-world problem would give it flexibility to choose among technical approaches, indeed to choose more than one if appropriate. Success would be measured in terms of progress in solving the problem.

The problems should not be too global (e.g., “reduce the amount of radioactive waste”) or too narrow (e.g., “make a particular technology work”). Sidebar 4.4 describes an example of a possible type of R&D center based on a recommendation from a recent NRC report (NRC, 2000c). The problem would determine the disciplines and the types of R&D (e.g., fundamental research, applied research, and development) and the number of investigators needed in each R&D center. Most centers probably would be highly multidisciplinary and would involve different types of R&D. For example, a center might include fundamental research, applied research, and perhaps some engineering research to demonstrate the efficacy and practicality of an idea. In addition, centers would be encouraged to involve participants from other agencies and other countries where appropriate. For some problems (e.g., those with high technical risks or of particular importance to EQ mission success), DOE might consider funding more than one center in order to increase the likelihood of success.

The R&D center would be expected to frequently consult with and involve its user-clients, which would generate a “technology pull” from them. In a sense, the center thus would become a co-owner of the problem. Large downstream development funding might be needed to achieve application in the field, but the center would take responsibility for seeing its own results applied. The R&D center would thus support a technology’s maturation through the development process (e.g., by consulting on problems that arise and perhaps doing some supportive research). In other words, the center would help bridge and narrow the gap between R&D and application (NRC, 2000b). R&D centers also would be encouraged to involve students and postdoctoral fellows to achieve the educational and training function described in Chapter 3 and mentioned above. Finally, the centers would be encouraged to coordinate and cooperate with related R&D activities, including EMSP and SC projects, work in other agencies, and work in other countries.

SIDEBAR 4.4 AN EXAMPLE OF AN R&D CENTER TO SOLVE SUBSURFACE CONTAMINATION PROBLEMS

A recent NRC report, *Research Needs in Subsurface Science, U.S. Department of Energy's Environmental Management Science Program,* included a recommendation very similar to the R&D centers recommended by this committee. Below is a quote from the Executive Summary of that report, describing field sites that could be used to address subsurface contaminants problems:

The committee recommends that [Environmental Management Science Program] program managers examine the feasibility of developing field research sites as one program component. Such sites could attract new researchers to the program, encourage both formal and informal multidisciplinary collaborations among the researchers, and facilitate the transfer of research results into application. These field sites could include contaminated or uncontaminated areas at major DOE sites; analog uncontaminated sites that have subsurface characteristics similar to those at contaminated sites; and even virtual sites comprised of data on historical and contemporary contamination problems. These sites could be established by the program itself or in cooperation with other research programs.

The establishment of field research sites is potentially expensive, especially if the sites are located in contaminated areas. Consequently, the establishment of such sites will require additional budget support beyond that required to fund individual research projects, and well beyond the amount of funding available to the program for new starts in fiscal year 1999. Moreover, the use of such sites will have to be evaluated periodically to determine whether they are adding value to the research effort, particularly given the cost of such sites relative to the total size of the program budget. (NRC, 2000c, p. 8–9)

Clearly, this recommendation is consistent with the committee's recommendation for R&D centers. A field research site could be the focus for a center that addressed a relevant set of problems. Because such a field-based center would receive R&D funding directly, it would differ from many field research sites established as user facilities. It also could provide a way to generate synergy with related Environmental Management Science projects and serve as a focus for center participants. It should be noted that the best R&D organizations are not always situated at the sites most in need of the R&D results. Centers should be awarded, established, and managed such that the best organizational talent is brought to bear on the problem.

Although the R&D centers would deal with currently intractable problems they would nevertheless be evaluated in terms of problem solution. The centers would be strongly encouraged to seek breakthroughs, even at the cost of some technical risk. To mitigate such risk and improve the probability of overall program success they would be responsible for seeking and developing alternative parallel paths. Each center would be overseen by an independent technical advisory committee familiar with the problem being addressed. Each center would be evaluated regularly on the basis of its progress in solving the assigned problem and overall technical soundness of its R&D. For funding to continue, the center would have to demonstrate first, that it is making progress in solving problems and, second, that it is sound scientifically and technically. For credibility, centers not making adequate progress toward solving EQ problems should be terminated by DOE, not by the Office of Management and Budget or Congress. Those R&D centers making adequate progress could be renewed if the problem remained important.

The committee did not examine in detail the funding that might be required for the R&D centers, but based on its members' experience as R&D managers and knowledge of DOE's EQ R&D portfolio, it believes that an appropriate figure for each center would be approximately $1–4 million annually for five years. The suggested funding range is meant to balance at least two considerations: (1) given the limited funds available and the desire to start several such centers, each must be small; and (2) on the other hand, each R&D center should be large enough to make progress toward problem solution. A problem calling for multidisciplinary R&D might need a larger R&D center. Such considerations also should help identify the problems to be addressed (i.e., the problems must be of a size appropriate to available funding).

Because the approach to EQ R&D recommended here would be new to DOE it should start small and grow only as long as justified by the problems. With the first set of R&D centers well underway, DOE could take steps to enlarge the program by selecting another small set of high-priority problems and repeating the process, fine-tuning the new centers to take advantage of lessons learned. The portfolio of problems addressed would grow as long as problem owners, stakeholders, DOE management, and other decision makers supported such efforts. By this process of continual improvement, EQ could build a portfolio of expertise to apply to its most important problems.

Need for Coordination of EQ R&D

R&D portfolio management, a recent innovation at DOE, begun in 1999 by its Under Secretary, covers the department's four programmatic business lines, with each having an R&D portfolio. The goal is "to integrate and strengthen the planning, management and administration" of the $8.0 billion DOE R&D enterprise (DOE, 2000i, p. 1). The means for achieving this goal are unclear, however. DOE documents do not address how the goal will be achieved with any specificity or depth (DOE, 2000b,i). DOE is aware of this deficiency; both the SLC review of the portfolio (DOE, 2000g) and a recent letter report by EMAB (DOE, 2000h) found that it was a good start but needed to be improved to achieve its goal.

As presented by DOE, the portfolio concept itself raises questions about whether it can achieve its stated goal. First, the portfolio is presented as being only a "context" for R&D: the portfolios "have no funding per se; they provide the context within which the funded programs and offices manage and execute their funding" (DOE, 2000i, p. 4). The R&D portfolios are descriptive tools, and no decision, budget, or priority-setting authority is associated with them. Because of this, no accountability is associated with them. These limitations are common to all the R&D portfolios, including the EQ portfolio.

EM, and its Office of Science and Technology, manages the great majority of the EQ R&D portfolio. Consequently, line managers could coordinate this part of the portfolio if given incentives to do so. However, other offices (see Sidebar 1.4) conduct some of the portfolio. In addition, as discussed below, there is much research in the Science portfolio in disciplinary areas of great interest to EQ programs, such as work on the movement of groundwater and on bioremediation.

DOE has taken a first, important step toward integrating its R&D programs through portfolio analysis. However, DOE's portfolio concept (i.e., as a context only) offers no way to reach across organizational or portfolio lines to coordinate R&D. The portfolios do little to cross DOE's existing organizational stovepipes. The relationship between EM and SC (which wholly owns DOE's Science portfolio) illustrates the situation. DOE's 2000 strategic plan directs SC to "advance basic research and the instruments of science that are the foundations for DOE's applied missions…to support long-term environmental cleanup and management at DOE sites…." (DOE, 2000f, p. 7). In other words, although it supports applied missions, its research is "basic" (i.e., it looks within science for its research questions and justifications), whereas EQ R&D must address external problems directly. Put another way, SC sees research as an end in itself, but for EQ research is a means to an end. As discussed briefly in Chapter 3, these different world views make cooperation and coordination correspondingly difficult, and unlikely without conscious, continual effort. The Environmental Management Science Program, which is administered jointly by EM and SC, demonstrates that such cooperation and coordination are possible, however.

DOE's portfolio approach also cannot compare programs between portfolios. For example, there is no common system for setting priorities or evaluating results. As the preceding example shows, different portfolios have very different metrics for success and different definitions of what is a worthwhile problem. Portfolio coordination and management are needed at high and low levels. At higher, strategic levels they are needed to deploy resources on the main problems. At lower, tactical levels they are needed to minimize duplication and overlap, to create synergies, and to ensure stakeholder involvement. All this is another way of saying that there is a need for alignment, value, and balance across and within portfolios, and at both strategic and tactical levels (realizing that because one cannot balance within the smallest program elements, balance is sought among such elements).

The generation of the R&D portfolios is a sound accomplishment that might provide a starting point for coordination. However, as presently described, DOE's portfolio management approach seems unlikely to achieve its goals. To be effective the portfolios will need to become a management tool, not just a descriptive tool. That is, the portfolio process would need to include explicit management functions and capabilities, especially accountability.

Finding: There is little evidence of effective coordination within the EQ R&D portfolio (e.g., for communication of results or for recommendations on priorities). Furthermore, there is little evidence of effective coordination between R&D portfolios.

Conclusion: At present DOE's R&D portfolio process is unlikely to achieve its goal to integrate and strengthen the planning, management, and administration of its $8 billion R&D enterprise.

DOE recognizes that "the portfolio process would benefit from improved coordination and a more integrated approach to…interportfolio activities" (DOE, 2000b, p. xiii). Although an understatement, this does indicate that the process may improve. Accordingly, the committee is reluctant to make a specific organizational recommendation that might limit DOE's options. In the past, the Under Secretary chaired a group, the R&D Council, whose members included the DOE leadership responsible for each of the four R&D portfolios. Although the status of the R&D Council remains uncertain following the 2000 election, the charter of such a group would allow it to oversee coordination of the EQ portfolio, as well as coordination between portfolios. Because its members have other duties and loyalties, however, such a group alone is an unlikely vehicle for coordination. The committee believes that such a group could serve as a forum for discussion and agreement on plans for coordination developed by the Under Secretary's staff.

The larger issue goes beyond specifics to whether DOE intends the portfolios to be more than a context (i.e., whether they should be actively managed). If they are to remain only descriptive (i.e., to reveal problems but not to address them), some other means for achieving the goals of improved R&D management must be found.

5

THE LEVEL OF INVESTMENT IN DEPARTMENT OF ENERGY ENVIRONMENTAL QUALITY RESEARCH AND DEVELOPMENT

In previous chapters the committee has identified the need for focused, vigorous, and sustained, research and development (R&D) activities to address the long-term problems faced by the Department of Energy's (DOE's) Environmental Quality (EQ) business line. The committee also has developed criteria to evaluate the adequacy of the EQ R&D portfolio, described the principal elements of the portfolio, and described how DOE could achieve and maintain a more effective, long-term R&D portfolio. This chapter identifies and refines measures that could be useful in determining an appropriate level of R&D investment.

EQ is DOE's second most expensive business line, accounting for $6.7 billion of the $19.7 billion DOE budget for fiscal year 2001 (see Table 5.1). The annual investment in EQ R&D is the smallest of the four business lines, however. For fiscal year 2001, funding for EQ R&D was about $298 million (4 percent of DOE's EQ budget), versus about $1.3 billion for R&D on energy resources (52 percent of DOE's Energy Resources budget), $3.4 billion for R&D on national security (49 percent of DOE's National Nuclear Security budget), and $3.0 billion for research on "science" (nearly all of DOE's Science budget). The smaller R&D investment in the EQ business line relative to that in the Energy Resources and National Nuclear Security business lines suggests that decision makers in DOE and Congress do not view EQ R&D as a high priority. Another indication that EQ R&D is not a high priority is a comparison of the trend of DOE EQ R&D spending with the trends in R&D spending in DOE's other business lines (see Figure 5.1). Figure 5.1 shows that from FY 1999 to FY 2001, R&D spending increased significantly in every DOE business line except EQ, where it was reduced by more than 8 percent over this same time period. The small increase in fiscal year 2001 suggests that the declining EQ R&D funding trend that occurred from 1995 to 2000, during which funding was reduced by nearly 50 percent (DOE, 2000b), may have stabilized or even reversed slightly. Even so, Figure 5.1 shows that in fiscal year 2001 R&D funding by DOE's other business lines increased significantly more than in EQ. These data are an indication that decision makers in DOE, the Office of Management and Budget, and Congress may not fully understand the magnitude and duration of many of the challenges faced by the EQ business line and the potential value of long-term R&D to address such challenges. The small amount of EQ R&D investment also is consistent with a business line that is required to meet many important short-term milestones, including regulatory requirements and the goals of DOE's accelerated clean-up plan (DOE, 1998). The data also may reflect the perception that past R&D investments have not resulted in many deployments of new technologies (U.S. House of Representatives, 2000).

TABLE 5.1 R&D Funding of Selected Federal Agencies (fiscal year 2001, current appropriations)

Agency/Business Line	Total Budget ($ billion)	R&D Budget	R&D as % of Budget
Environmental Protection Agency	7.8[a]	$686 million[a]	9
Department of Defense	288[a]	$41.8 billion[a]	15
Department of Energy (total)	19.7[b]	$8.0 billion[a]	41
Science	3.2[b]	$3.0 billion[a]	>90
National Nuclear Security	7.0[b]	$3.4 billion[a]	49
Energy Resources	2.5[b]	$1.3 billion[a]	52
Environmental Quality	**6.7[b]**	**$298 million[c]**	**4**
Corporate Management, Other	0.3[b]	–	–

Data Sources:
[a]AAAS, 2001.
[b] Department of Energy Office of Chief Financial Officer (http://www.cfo.doe.gov/budget/02budget/3-pager.pdf)
[c]K.Chang, DOE (personal communication).

Determining an appropriate level of R&D investment requires clarity on three principles:

- **The level of investment depends on the scope of DOE's EQ mission.**
- **The level of investment must take into account the balance to be drawn between spending limited resources on R&D and other possible applications of those resources in meeting other EQ goals and commitments.**

- **There are no formulas or mechanistic ways that by themselves provide or justify a specific funding level recommendation.** Nonetheless, the committee discusses two techniques (benchmarking and investment indicators) that DOE should use as guides in determining an appropriate level of EQ R&D investment.

Each of these principles is discussed below.

DEFINING THE GOALS AND OBJECTIVES OF THE EQ MISSION

Broad based support for EQ R&D investment first requires a clear and compelling presentation of, and commitment to, the goals and objectives of the EQ mission. As discussed in Chapter 2, there is currently some lack of clarity and consistency in DOE's EQ goal and objectives, and this deserves careful consideration and clarification. The similar and

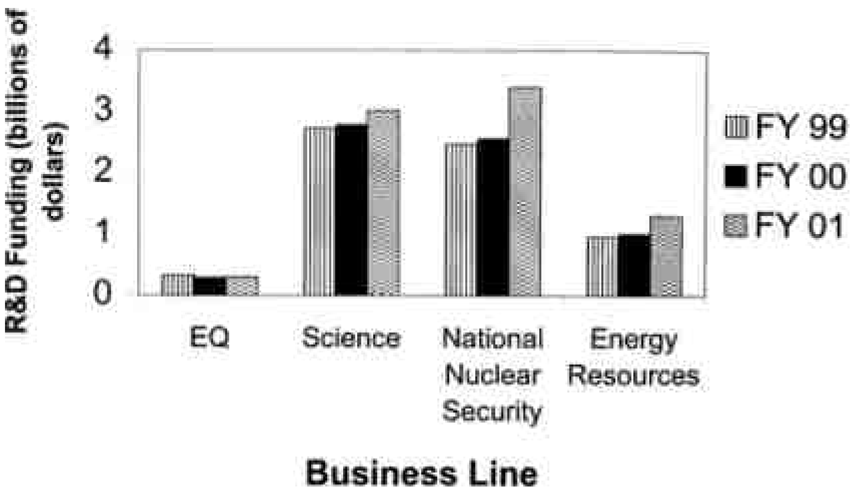

FIGURE 5.1. DOE Business Line R&D Spending by Year (in billions of dollars). Data for fiscal year 2001 (FY 01) are estimates based on appropriations. Data from 1999 and 2000 for all business lines are from DOE's R&D Portfolio Overview (DOE, 2000i). Data from 2001 for the National Nuclear Security, Science, and Energy Resources business lines are from AAAS (2001); 2001 data for EQ are from K.Chang, DOE (personal communication).

overlapping but clearly differing descriptions of the EQ goal and objectives over the past three years makes it difficult to both identify and defend the appropriate levels of R&D investment.

To resolve the matter, the committee has recommended that DOE develop strategic goals and objectives for its EQ business line that incorporate a more comprehensive, long-term view of DOE's EQ responsibilities. If DOE accepts this recommendation, it will almost certainly need to re-examine the level of EQ R&D investment. Once clear and enduring goals and objectives are defined, methods such as those discussed later in this chapter should be a base for analyzing whether the level of R&D funding is appropriate for meeting DOE's EQ responsibilities. Of course, funding alone cannot ensure that EQ R&D will be effective. Effective portfolio management, such as that described in Chapter 4, is an important first step in ensuring that DOE's EQ R&D investments are used effectively.

BALANCING R&D INVESTMENTS WITH OTHER IMPORTANT EQ NEEDS

After clear and appropriate goals and objectives have been defined, determining the level of R&D investment will require difficult tradeoffs from DOE managers and others. There are many important short-term issues that call for high-priority allocation of funds. In EM, often reinforcing or driving these needs are milestones associated with existing compliance agreements between DOE and state environmental regulatory authorities, and concomitant expectations of the affected communities and their representatives. Congressionally mandated milestones are major drivers of much of the Office of Civilian Radioactive Waste Management's (RW's) program activities. In such situations, allocating funds to R&D can be seen as taking resources away from meeting short-term requirements or compliance agreements to support activities that are, by their very nature, longer term and more uncertain in their ultimate benefits. It is incumbent upon DOE leadership to make clear to all EQ stakeholders the value of a robust and sustained R&D portfolio in addressing the most challenging EQ problems.

DOE has made initial steps in recognizing this required balance through the creation of the Environmental Management Science Program (EMSP), the focus areas and crosscutting programs within EM's Office of Science and Technology (OST), and R&D programs in RW and the Office of Nuclear Energy, Science and Technology (NE). However, most of these EQ R&D programs have not been characterized by a history of "strong, stable funding for a portfolio of research investments that is diverse in terms of funders, performers, time horizons, and motiva tions" that is needed for effective "capitalization" of R&D results (COSEPUP, 1999a, p. 4).

For example, decreases in funding for the EMSP program, together with significant "mortgages" imposed on the program from previous years' awards that were not fully funded (see discussion in NRC, 1997), have significantly reduced the number of new grants that can be awarded (see Table 5.2). As a result, in every year since fiscal year 1998, the EMSP program has chosen to focus all of its new grants in two (or fewer) technical areas (which change from year to year), rather than offering new grants annually in all technical areas.[1] Such discontinuities in funding in specific technical areas from year to year, along with decreases in funding, is not an effective strategy for "expand[ing] the core of 'committed cadre' of investigators who are knowledgeable about EM's problems" (NRC, 1997, p. 4), one of the stated goals of the EMSP program.

In addition, the funding levels of some EQ R&D programs have been

TABLE 5.2 Environmental Management Science Program Funding History (Fiscal Year 1996 to 2000)

	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000
Total Budget (in $ millions)	50.0	48.0	48.0	47.0	32.0
Funds available for new starts (in $ millions)	45.9	21.0	10.0	10.3	5.4
Current year funds committed by previous awards ("mortgage", in $ millions)	0.0	23.3	34.4	31.8	22.6
Number of new awards	136	66	33	39	

Source: DOE, 2000m.

[1]In fiscal year 1998, EMSP issued two solicitations in the areas of decontamination and decommissioning and high-level waste; in fiscal year 1999, EMSP issued a single solicitation for subsurface contamination and vadose zone issues; in fiscal year 2000, EMSP issued no solicitations for new grants and awarded 31 renewals; and in fiscal year 2001, EMSP issued two solicitations in the areas of deactivation and decommissioning and highlevel waste.

developed largely from the "bottom up" and have focused on short-term needs identification (NRC, 1999a), and some have been characterized by significant changes from year to year. For example, a recent NRC committee found that the success of OST's Subsurface Contaminants Focus Area (SCFA)

> has been limited in part by large budget swings. In fiscal year 1998, SCFA's budget was reduced to a level that was insufficient to support significant progress on the development of innovative remediation technologies. The budget level was cut from a 1994 level of $82 million to a 1998 level of $15 million, which included a $5 million congressional earmark, leaving an effective budget of $10 million. This budget was inadequate to fund the types of large-scale demonstrations needed to transition innovative remediation technologies from the research and development phase to full-scale application. It also was too small to allow open bidding for project funding. The fiscal year 1999 budget of $25 million, while representing a significant increase, will allow for funding of only a limited number of projects. (NRC, 1999b, p. 247)

The purpose of citing these cases is not to criticize DOE leadership, as a decision to concentrate limited funding in a few high-priority areas to establish critical research foci is a logical alternative to funding only a few projects in all technical areas. Rather, these cases are provided as examples of some of the difficult tradeoffs that must be made when only limited resources are available.

Given the reasonableness of priority on near-term performance, it is likely that the lack of a well-documented, accepted approach for determining long-term R&D funding levels will lead to strong pressure on program managers to defend and possibly reduce EQ R&D investments.

DETERMINING AN APPROPRIATE LEVEL OF R&D INVESTMENT

The committee was asked to provide guidance on how to determine the level of future investments in EQ R&D. It has not been possible to identify an analytic or quantitative approach to establish an appropriate level of R&D funding for the EQ business line, because funding levels are in the end a policy decision that involves multiple tradeoffs. However, there are two general techniques that, together, could be used for this purpose: (1) benchmarking against other mission-driven R&D efforts, both nationally and internationally; and (2) applying a set of investment indicators based closely on the adequacy criteria developed in Chapter 3. The committee provides an overview of these techniques in the sec tion that follows. The committee also illustrates by example how each of these techniques could be applied to the EQ R&D portfolio. The committee was not asked to recommend an appropriate level of R&D investment or to recommend that the current level of investment be increased or decreased; however, the committee strongly encourages DOE to conduct its own analyses of EQ R&D funding using these techniques.

Benchmarking Against Other Mission-Driven R&D Efforts

Benchmarking R&D investment levels with competitors and other similar R&D programs is a standard method used in industry (NRC, 1999a; DOE, 2000j). Benchmarking also can be used to compare the quality and impact of research (as well as the level of R&D investments) in one country with research in other countries, as discussed in reports from the National Academies' Committee on Science, Engineering, and Public Policy (COSEPUP, 1993, 2000). Its recent report, *Experiments in International Benchmarking of U.S. Research Fields* (COSEPUP, 2000), provides a detailed description of the methodology to be used in such benchmarking exercises. There is a large volume of information describing and analyzing R&D funding in the federal government and in the private sector. Although there are marked and understandable differences between DOE's EQ programs and other government and industry R&D programs, benchmarking could provide one meaningful measure for discerning a range of reasonable R&D investment levels for the EQ business line.

The following sections discuss two types of benchmarking and applies them to select EQ R&D funding data: (1) benchmarking total R&D funding and (2) benchmarking the balance of R&D funding by stage of R&D maturity.

Benchmarking Total R&D Funding

An informative exercise is to compare total EQ R&D funding (both the level of investment and recent funding trends) with that in the three other DOE business lines. As mentioned earlier in this chapter, the National Nuclear Security and Energy Resources business lines both devote approximately 50 percent of their funds to R&D (see Table 5.1). The Science business line, not surprisingly, devotes almost all of its funds to research. Although the current EQ business line has a particular programmatic focus, the 4 percent dedicated to EQ R&D has been called into question by many, including DOE in its department-wide summary of the R&D portfolio effort, *R&D Portfolio Overview,* which states that "current [EQ R&D] funding may not adequately support a long-term inte grated research program" (DOE, 2000i, p. 25). The Strategic Laboratory Council's adequacy analysis (DOE, 2000g) and a letter report from the Environmental Management Advisory Board (DOE, 2000h) also have concluded that the level of DOE's EQ R&D funding is inadequate (see Appendix C). Two other groups, the Washington Advisory Group and a National Research Council committee also came to a similar conclusion about the level of funding for subsurface science research in the EQ R&D portfolio (NRC, 2000c; WAG, 1999).

Benchmarking of recent EQ R&D funding trends against funding trends for DOE's other R&D portfolios also is informative because it can help distinguish trends that are DOE-wide from those that are unique to the EQ R&D portfolio. Figure 5.1 shows that EQ R&D funding has declined significantly at the same time that R&D funding for DOE's other business lines has increased. Figure 5.2 illustrates that this reduction is not limited to EM (which dominates total EQ R&D funding data); EQ R&D funding in both RW and NE also has declined significantly in recent years. These data are a strong indication that EQ R&D funding decreases do not simply reflect department-wide (or national) budgetary constraints. DOE, in its *R&D Portfolio Overview,* noted the decline in EQ R&D funding as follows: "The downward funding trend is incongruous

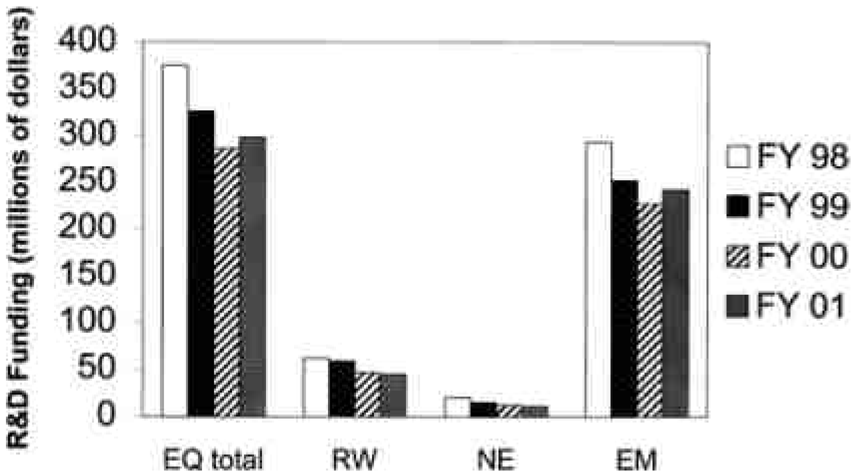

FIGURE 5.2. EQ R&D Spending by Year (in millions of dollars). Data for fiscal year (FY) 1998, 1999, 2000 are from DOE's Environmental Quality Research and Development Portfolio (DOE, 2000b). Data for FY 2001 are from K.Chang, DOE (personal communication).

with upward trends in life-cycle costs and programmatic risk levels associated with current cleanup projects. Further advancements in science and the use of new technologies will be required to meet current cost projections, much less reduce life-cycle costs" (DOE, 2000i, p. 25).

The R&D budgets from other mission agencies also provide a useful comparison. Table 5.1 includes fiscal year 2001 R&D funding data for the U.S. Environmental Protection Agency and the Department of Defense (DOD) in comparison with DOE as a whole, and for DOE's four programmatic R&D business lines. Again, the percentage of the DOE EQ budget spent on R&D is significantly lower than that for other U.S. mission agencies.

The National Science Board's report, *Science and Engineering Indicators 2000* (NSF, 2000) contains extensive data on allocations of R&D funds by federal agencies and the private sector. These data also can provide a context for EQ R&D funding decisions. For example, data on R&D as a percentage of federal budget authority by function is summarized in Table 5.3. These data show that the percentage of DOE's EQ business line budget spent on R&D (4 percent) is significantly lower than the average for the federal government as a whole in the area of natural resources and environment (8.1 percent).

The Industrial Research Institute tracks data on R&D The Industrial Research Institute tracks data on R&D intensity (defined as the ratio of R&D funding to net sales) for different industrial sectors (Table 5.4). Although research intensity is not directly comparable with the percentage of federal program budgets allocated to R&D, the Industrial Research Institute data show that research intensity is highest in knowledge-intensive industries such as software and pharmaceuticals, whereas research intensity is lowest for such mature industries as petroleum and construction. Given the unique and enduring nature of many of DOE's

TABLE 5.3 R&D as a Percentage of Federal Budget Authority by Function

	R&D Spending as Percentage of Budget Authority
General science	73.1
Space research and technology	67.3
National defense	13.4
Agriculture	10.8
Health	10.2
Natural resources and environment	8.1
Transportation	3.4

Source: NSF, 2000; Table 2–2, p. 2–12.

EQ problems (as discussed in Chapter 3), the committee believes that the EQ business line has a fairly knowledge-intensive long-term mission. This is another indication that the EQ R&D budget may be anomalously low with respect to other federal R&D efforts.

TABLE 5.4 Research and Development Intensitya Global Firms (1997)

Sector	R&D Intensity
Software	13.67
Pharmaceuticals	12.04
Medical Instruments	9.67
Scientific Equipment	6.40
Electronics	6.30
Computers	5.96
Chemicals	4.76
Aerospace	4.55
Automobile	4.19
Telecommunications	3.62
Soaps	3.55
Heavy Industries	2.48
Building Materials	2.04
Food	1.34
Metal and Metal Products	1.16
Gas & Electricity	1.00
Tobacco	0.95
Forest and Paper Products	0.90
Engineering and Construction	0.73
Petroleum	0.66

[a]The ratio of R&D funding to net sales.
Source: Bowonder and Yadav, 1999.

Benchmarking the Balance of R&D Funding

In theory, benchmarking also can be used to compare the balance of R&D investments in the EQ R&D portfolio with that of other agencies and the private sector. As an example, the committee discusses one element of R&D balance, the percentage of total R&D spending that supports basic research. The National Science Board's report, *Science and Engineering Indicators* 2000, summarizes fiscal year 2000 funding levels for basic research and applied R&D for different types of federal R&D (see Table 5.5). For natural resources and environment, for example, approximately 9 percent of R&D funding supported basic research. For en ergy, approximately 3 percent of R&D funding supported basic research. The Industrial Research Institute tracks similar data for industry, and its data show that in 2000, approximately 7 percent of industrial R&D funding supported basic research.

TABLE 5.5 Budget Authority for R&D by Function and Character of Work: Anticipated Levels for Fiscal Year 2000 (millions of dollars)

Budget Function	Basic Research	Applied Research and Development	R&D Total	Basic Research as a Percentage of R&D Total
Total	18,101	57,314	75,415	24.0
National Defense	1,152	36,559	37,710	1.7
Nondefense (total)	16,949	20,755	37,704	45.0
Health	8,590	7,234	15,824	54.3
Space Research and Technology	1,841	6,581	8,422	21.9
Energy	46	1,302	1,348	3.4
General Science	4,710	241	4,951	95.1
Natural Resources and Environment	175	1,769	1,944	9.0
Transportation	634	1,206	1,840	34.5
Agriculture	736	786	1,522	48.4
All other	218	1,636	1,853	11.8

Source: NSF, 2000, Table 2–3.

Data on the distribution of EQ R&D funding for EM in fiscal year 2000 by focus area, including EMSP funding directed at each focus area (the only significant part of the EQ R&D portfolio with funding data broken down by stage of R&D) are summarized in Table 5.6. The committee has used these data to calculate basic research spending as a percentage of total R&D investment for each of OST's five focus areas, with the following results:

Transuranic and Mixed Waste	4%
Subsurface Contaminants	18%
Tanks	22%
Deactivation and Decommissioning	28%
Nuclear Materials	44%

These data show that, with the exception of the Transuranic and Mixed Waste Focus Area, most of OST's focus areas invest a significant

TABLE 5.6 DOE's Office of Science and Technology Fiscal Year 2000 EQ R&D Funding by Stage of Maturity (in $ thousands)

Focus Area	Basic Research	Applied Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration	Deployment	Total
Tanks	13,110	4,800	3,500	4,500	12,900	10,800	8,000	57,610
Transuranic and Mixed Waste	1,228	858	5,180	6,183	5,443	6,334	3,914	29,140
Nuclear Materials	3,189	0	750	950	1,295	0	1,053	7,237
Subsurface Contamination	8,892	0	0	4,500	7,300	12,200	17,300	50,192
Deactivation and Decommissioning	3,598	1,646	1,646	2,171	3,264	4,608	12,671	12,672

Source: L.Nichols, DOE (personal communication). Basic research funding includes Environmental Management Science Program funding applicable to each focus area.

fraction of their R&D resources in basic research. This probably reflects the significant decrease in total EQ R&D spending over the past few years (see Figure 5.1), coupled with recent congressional pressures to fund basic research within the EMSP program. It should be noted that these data are based on how OST program managers chose to categorize their R&D funding into the 7 stages of R&D tracked by OST, and that this categorization was done relatively quickly at the request of this committee. The committee suspects that some R&D classified as basic research could have been classified as applied research, which would tend to lower the percentages given above. It also is important to recognize that the data do not include relevant basic research funded by DOE's Office of Science, which if incorporated would tend to increase the percentages given above. Due to the significant uncertainties discussed above, the committee cautions the reader not to draw significant conclusions from this comparison. However, the calculation illustrates how DOE could assess the balance of its R&D investments (or at least specific elements of balance) through benchmarking.

Conclusion: Benchmarking with other mission-driven federal R&D efforts could provide perspective on whether the EQ R&D budget is too high or too low. It could also help to explain and justify the level of future budget requests to decision makers within DOE, the Office of Management and Budget, and Congress and to other interested parties.

Recommendation: DOE should benchmark the EQ R&D budget against other mission-driven federal R&D programs. Such benchmarking exercises should have participation or review by outside experts. Proposed budgets should be presented in the context of benchmarking, and significant deviations from the information gained through benchmarking should be explained.

Such benchmarking should take into account that DOE has a separate basic research program that includes some research activities that are related to (though not directed to) DOE's EQ mission. It also is very important that this analysis to be transparent and credible (COSEPUP, 1999a). Whereas no correct level of investment exists, having a review by internal and external experts can help provide independent advice and enhance credibility in justifying an R&D investment level.

Indicators of an Adequately Funded R&D Portfolio

In Chapter 3, the committee developed criteria to evaluate the adequacy of the EQ R&D portfolio. These criteria were based on what the committee considered essential elements of a successful, long-term EQ R&D portfolio. And, although they were not framed in terms of R&D investment, they can be re-packaged slightly as investment indicators. The level of EQ R&D investment should be sufficient for the EQ R&D portfolio to:

- address all critical areas of science and technology that are required to address EQ goals and objectives;
- support the accomplishment of closely related DOE and national missions;
- include R&D to develop technical alternatives in cases where (1) existing techniques are expensive, inefficient, or pose high risks to health or the environment; or (2) techniques under development have high technical risk;
- produce results that could transform the understanding, need, and ability to address currently intractable problems and lead to breakthrough technologies;
- leverage R&D conducted by other DOE business lines, the private sector, state and federal agencies, and other nations to address EQ goals and objectives;
- help narrow and bridge the gap between R&D and application in the field;
- improve performance, reduce risks to human health and the environment, decrease cost, and advance schedules.
- achieve an appropriate balance between addressing long-term and short-term issues;
- involve a diversity of participants from academia, national laboratories, other federal agencies, and the private sector, including students, postdoctoral associates, and other early-career researchers;
- include annual new starts, extensions of promising R&D, and periodic new initiatives.

Meeting such criteria is an important indication of an appropriately formulated R&D portfolio. Although the level of R&D investment alone cannot guarantee the achievement of these indicators, the level of funding should not preclude their achievement.

Finding: It has not been possible to identify an analytic or quantitative approach that is suitable for establishing an appropriate level of R&D funding for the EQ R&D portfolio.

Conclusion: Investment indicators based on the functions of a successful EQ R&D portfolio can provide useful guides for the appropriate funding level.

Recommendation: DOE should use investment indicators, together with benchmarking techniques, to help determine the appropriate level of EQ R&D investments.

These investment indicators should provide a useful guide to the appropriate range of EQ R&D funding levels. As discussed in Chapter 3, it is also particularly important that DOE's process for arriving at appropriate level of R&D funding consider the contributions of EQ R&D to meeting DOE's other missions (particularly, its National Nuclear Security and Energy Resources missions), and should be based on a retrospective examination of the results of past EQ R&D.

CONCLUSION

DOE's EQ R&D portfolio must be recognized as centrally important to DOE's EQ and other missions and as an enduring responsibility of the department. R&D success requires an adequate, stable, and predictable level of funding. A well-designed, sufficiently funded, and well-implemented EQ R&D portfolio is necessary, but not sufficient, to assure that the potential value of R&D in addressing DOE's EQ problems is achieved. Many other features also must be present, including technically competent and trusted R&D program managers; effective relationships among problem holders, R&D managers and researchers; good communication of R&D results; and incentives for R&D results to be used in solving problems.

An effective portfolio also requires close and trusting relationships among the responsible DOE headquarters and local officials, contractors at the sites, state regulatory officials, and stakeholders such as the affected community. The nature of successful EQ R&D is to present opportunities to reduce risks to workers and the public, improve schedules, decrease costs, and solve problems (see discussion in Chapter 3). But it also can require re-addressing existing agreements, changing schedules, dealing with periods of uncertainty, and revisiting expectations. All of these factors must be resolved for DOE's EQ R&D to achieve its goals. An EQ R&D portfolio that is well conceived, effectively managed, adequately and consistently funded, and championed by DOE leadership is essential to success in achieving the DOE EQ mission.

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APPENDIX A

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

Gregory R.Choppin, *Chair,* is currently the R.O. Lawton Distinguished Professor of Chemistry at Florida State University. His research interests involve the chemistry of the f-elements, the separation science of the f-elements, and the physical chemistry of concentrated electrolyte solutions. During a postdoctoral period at the Lawrence Radiation Laboratory, University of California, Berkeley, he participated in the discovery of mendelevium, element 101. His research and educational activities have been recognized by the American Chemical Society's Award in Nuclear Chemistry, the Southern Chemist Award of the American Chemical Society, the Manufacturing Chemist Award in Chemical Education, the Chemical Pioneer Award of the American Institute of Chemistry, a Presidential Citation Award of the American Nuclear Society, the Bequerel Award in Nuclear Chemistry of the British Royal Society of Chemistry, and honorary D.Sc. degrees from Loyola University and the Chalmers University of Technology (Sweden). Dr. Choppin has served on the National Research Council's (NRC's) Board on Chemical Sciences and Technology. He received a B.S. degree in chemistry from Loyola University, New Orleans, and a Ph.D. degree from the University of Texas, Austin.

David E.Adelman serves as staff attorney for the international and nuclear programs at the Natural Resources Defense Council. Prior to joining the Council in 1998, Dr. Adelman served as an associate with the law firm of Covington & Burling, focusing on environmental and intellectual property litigation and regulatory matters. He is a member of the Department of Energy's (DOE's) Environmental Management Advisory Board. Dr. Adelman received his B.A. in chemistry and physics from Reed College, his Ph.D. in chemical physics from Stanford University, and his J.D. from Stanford Law School.

Radford Byerly, Jr. retired as vice-president for public policy of the University Corporation for Atmospheric Research after a distinguished career in academia and government, specializing in science management and policy. Dr. Byerly is the co-author of several recent papers on federal research and development (R&D) policy, including "Beyond Basic and Applied" (Physics Today, 1998) and "The Changing Ecology of United States Science" (Science, 1995). Among his many positions, Dr. Byerly has worked at the National Institute of Standards and Technology (then the National Bureau of Standards) in the environmental measurement and fire research programs; has served as chief of staff of the U.S. House of Representatives Committee on Science and Technology; and was director of the University of Colorado's Center for Space and Geosciences Policy. He currently serves on the American Association for the Advancement of Science's Committee on Science, Engineering, and Public Policy and serves on National Science Foundation site visit committees and review panels. He is a member of the Board of Associated Universities for Research in Astronomy, and has served on the Committee on the Department of Energy—Office of Science and Technology's Peer Review Program. He received his Ph.D. in physics from Rice University.

William L.Friend is a corporate director, consultant, and educator drawing on his background of over 40 years in chemical engineering and executive management in the international engineering-construction industry. He recently retired as executive vice president of the Bechtel Group. During his tenure there, he was responsible for Bechtel's DOE/Department of Defense/National Aeronautics and Space Administration activity, including environmental remediation work at the Hanford reservation and other DOE sites. He currently chairs the University of California President's Council for the National Labs. Mr. Friend was elected to the National Academy of Engineering for leadership in the development of new technologies and their application in commercial facilities. He received his Bachelors Degree from Polytechnic University and holds a Masters in Chemical Engineering from the University of Delaware.

Thomas H.Isaacs is director of Lawrence Livermore National Laboratory's Office of Policy, Planning, and Special Studies and chair of its Council on Energy and Environmental Systems. Mr. Isaacs is responsible for long-range strategic and institutional planning and conducts policy and technology studies for the laboratory. Prior to joining the laboratory in 1996, he held various positions within DOE, including executive director of DOE's Advisory Committee on External Regulation of DOE Nuclear Safety and Director of Strategic Planning and International Programs for the Department's Radioactive Waste

Program. Mr. Isaacs received a B.S. in chemical engineering from the University of Pennsylvania and a M.S. in engineering and applied physics from Harvard University.

James H.Johnson, Jr. is professor and dean of the College of Engineering, Architecture, and Computer Sciences at Howard University. Dr. Johnson's research interests have focused mainly on the reuse of wastewater treatment sludges and the treatment of hazardous substances. His research has included the refinement of composting technology for the treatment of contaminated soils, chemical oxidation and cometabolic transformation of explosive-contaminated wastes, biodegradation of fuel-contaminated groundwater, the evaluation of environmental policy issues in relation to minorities and development of environmental curricula. Currently, he serves as associate director of the Great Lakes and Mid-Atlantic Center for Hazardous Substance Research and as a member of the Environmental Protection Agency's (EPA's) Office of Research and Development, Board of Science Counselors and the NRC's Board on Radioactive Waste Management. He has served on the Environmental Engineering Committee of EPA's Science Advisory Board and NRC's Committee on the Remediation of Buried and Tank Wastes. Dr. Johnson is a registered professional engineer in the District of Columbia, a Diplomate in the American Academy of Environmental Engineers and a fellow of the American Society of Civil Engineers. He received a B.S. from Howard University, a M.S. from University of Illinois, and a Ph.D. from the University of Delaware.

Charles Kolstad is a professor of environmental economics at the University of California, Santa Barbara, where he is jointly appointed in the Department of Economics, the Ben School of Environmental Science and Management, and the Environmental Studies Program. Dr. Kolstad's current research focuses on the role of information in environmental decision making and regulation, and environmental valuation theory. He also has a major research project on the role of uncertainty and learning in controlling the precursors of climate change. His past work on energy markets has focused on coal and electricity markets, including the effect of air pollution regulation on these markets. Dr. Kolstad is president-elect of the Association of Environmental and Resource Economics and editor of the journal *Resource and Energy Economics.* He is also a member of EPA's Clean Air Act Compliance Analysis Committee, and has served on numerous other advisory boards, including the Environmental Economics Advisory Committee of EPA's Science Advisory Board. Dr. Kolstad has served on the NRC's Board on Energy and Environmental Systems, the Energy Engineering Board, and the Committee on Fuel Economy of Automobiles and Light Trucks. He received his B.S. from Bates College, his M.A. from University of Rochester, and his Ph.D. from Stanford University.

C.Edward Lorenz recently retired as vice president of research and development for DuPont Chemicals, of E.I.DuPont de Nemours & Co. Dr. Lorenz began his career at DuPont as a research chemist, and held a variety of research and management positions throughout his four-decade career with the firm. He holds several patents in the fields of catalysis, monomer, and polymer synthesis. Dr. Lorenz is a member of the American Chemical Society, the Society of the Chemical Industry, the New York Academy of Sciences, and the American Association for the Advancement of Science. He has served on Industry Advisory Committees for New York University, the University of Georgia, and the University of Tennessee. Dr. Lorenz received his B.S. and Ph.D. degrees in organic chemistry from New York University.

Michael Menke is a consultant at Hewlett-Packard. Prior to joining Hewlett-Packard, Dr. Menke was president of Value Creation Associates where he worked with research-driven companies in developing successful business and technology strategies, re-engineering their R&D management and new product development processes, and improving R&D productivity. He was a founding partner of Strategic Decisions Group and led its R&D and pharmaceutical industry practices, as well as its groundbreaking benchmark study of the best decision practices of the world's leading companies. Dr. Menke has published extensively and speaks frequently on a wide range of business and innovation management topics. His consulting assignments include new product commercialization strategies, product sales forecasting and capacity planning, R&D portfolio management, and evaluation of new high-technology products and processes in a wide range of industries, including biotechnology, chemicals, medical devices, and pharmaceuticals. Dr. Menke has served on the NRC's Committee on Prioritization and Decision Making in the U.S. Department of Energy Office of Science and Technology. He received a B.A. in physics from Princeton, a M.Sc. in applied math from Cambridge, and a Ph.D. in physics from Stanford University.

Warren F.Miller recently retired from his position as a senior advisor to the director of Los Alamos National Laboratory and professor-in-residence in the Department of Nuclear Engineering at the University of California, Berkeley. Dr. Miller has extensive experience in the area of R&D program management. He served in a variety of management positions at Los Alamos National Laboratory, including deputy director for science and technology (1996–1999), director of science and technology base programs (1993–1995), associate laboratory director for research and education (1992–1993), deputy laboratory director (1986– 1988), associate laboratory director for energy programs (1981–1982), and as deputy associate laboratory director for nuclear programs (1980– 1981). He also served as the E.H. and M.E.Pardee Professor in the Department of Nuclear Engineering at the University of California, Berkeley, from 1988 to 1992. Dr. Miller received a B.S. in engineering science from the U.S. Military Academy and his M.S. and Ph.D. degrees in nuclear engineering from Northwestern University. Dr. Miller was elected to the National Academy of Engineering in 1996.

Victoria Tschinkel is senior consultant for environmental issues at the law firm of Landers and Parsons, Tallahassee, Florida. In this position, she specializes in assisting corporate clients on strategic environmental issues and represents clients before agencies and the Legislature. Ms. Tschinkel served as Secretary of the Florida Department of Environmental Regulation (1981–1987) and has held positions on a number of national advisory councils such as the National Environmental Enforcement Council and the Energy Research Advisory Board. She is a member of the National Academy of Public Administration and continues to serve as a member of both state and national advisory councils. She is a director of Phillips Petroleum Company, Resources for the Future, and the Center for Clean Air Quality. She currently serves as a member of the NRC's Board on Radioactive Waste Management, and is a former member of the Commission on Geosciences, Environment, and Resources. Ms. Tschinkel has served on numerous NRC study committees, including the Committee to Evaluate the Science, Engineering, and Health Basis of the Department of Energy's Environmental Management Program, the Committee on Remedial Action Priorities for Hazardous Waste Sites, and the Committee to Provide Interim Oversight of the DOE Nuclear Weapons Complex. Ms. Tschinkel received her B.S. degree in zoology from the University of California, Berkeley.

APPENDIX B

PARTICIPANTS LIST AND AGENDA FOR AUGUST WORKSHOP

COMMITTEE MEMBERS

Gregory R.Choppin, *Chair,* Florida State University, Tallahassee

Teresa Fryberger,[1] *Vice-Chair,* Brookhaven National Laboratory, Upton, New York

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C.Edward Lorenz, E.I.Dupont De Nemours & Co. (retired), Wilmington, Delaware

Michael Menke, Hewlett-Packard, Palo Alto, California

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Victoria Tschinkel, Landers and Parsons, Tallahassee, Florida

SPEAKERS

John Gibbons, Office of Science and Technology Policy (retired), The Plains, Virginia

Ivan Itkin, U.S. Department of Energy, Washington, D.C.

[1] Recused herself from committee activities in November 2000 and resigned from committee in January 2001 after accepting a management position within the Department of Energy Office of Environmental Management.

David Heyman, U.S. Department of Energy, Washington, D.C.
James Owendoff, U.S. Department of Energy, Washington, D.C.

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Mike Pfister, Coleman Federal, Fairfax, Virginia
Rod Quinn, Battelle-Albuquerque, New Mexico
Paul Smith, U.S. Department of Energy, Germantown, Maryland
Gary Tritle, Lakeway, Texas
John Veldman, Westinghouse Savannah River Company, Aiken, South

Carolina

Jef Walker, U.S. Department of Energy, Germantown, Maryland
C.Herb Ward, Rice University, Houston, Texas
Susan Wiltshire, Hamilton, Massachusetts
Nicholas Woodward, U.S. Department of Energy, Germantown, Maryland
Raymond Wymer, Oak Ridge, Tennessee

Building a Long-Term Environmental Quality Research and Development Program in the U.S. Department of Energy

Workshop—August 23, 24 & 25, 2000

National Academies
National Academy of Sciences Building
2101 Constitution Avenue
Washington, DC 20418

PUBLIC AGENDA

Wednesday, August 23

OPEN SESSION (Committee, Guests, and NRC Staff)—Lecture Room

8:30 a.m.	Welcome and Introductions *Gregory Choppin,* Chair Teresa *Fryberger,* Vice-Chair
8:45 a.m.	Overview of DOE's R&D Portfolio Process and Study *David Heyman,* Senior Advisor to the Secretary, Technology, Policies, and Partnerships.
9:15 a.m.	Discussion
9:30 a.m.	Office of Environmental Management's Long-Term Environmental Quality R&D Needs *James Owendoff,* Principal Deputy Assistant Secretary for Environmental Management
9:50 a.m.	Discussion
10:00 a.m.	Office of Civilian Radioactive Waste Management's Long-Term Environmental Quality R&D Needs *Ivan Itkin,* Director of Office of Civilian Radioactive Waste Management
10:15 a.m.	Discussion
10:30 a.m.	BREAK

10:45 a.m.	Evaluating the Benefits of Long-Term Environmental Quality R&D *Jack Gibbons,* Former Assistant to the President for Science and Technology, and Former Director, OSTP
11:00 a.m.	Discussion
11:15 a.m. Working	Introduction to R&D Portfolio Analysis and Overview of Group Tasks *Michael Menke,* Committee Member
11:45 a.m.	Discussion
12:00 noon	LUNCH available in the Refectory.
NOTE: Working Group Leads, Chair and Vice-Chair Meet for Lunch in CLOSED SESSION (Committee and NRC Staff ONLY)—Room 150	
1:00 p.m.	Break into Working Groups A, B, and C for 1-hour Discussion of Morning Presentations and Working Group Charges (Lecture Room, Room 150, Room 180)
2:00 p.m.	Brief Plenary Discussion of Working Group Discussions (10 minute reports/10 minute discussion for each working group)
2:30 p.m.	Break into Working Groups for First Working Session (see description of working group tasks)
4:45 p.m.	Working Groups Report Back to Plenary Session
5:45 p.m.	Adjourn
6:00 p.m.	Reception (Great Hall)

Thursday, August 24

CLOSED SESSION (Committee and NRC Staff ONLY)—Room 150	
7:30 a.m.	EQ Committee Meets for Breakfast
OPEN SESSION (Committee, Guests, and NRC Staff)—Lecture Room	

8:30 a.m.	Plenary Session: Overview/instructions *Gregory Choppin, Chair* *Teresa Fryberger, Vice-Chair*
8:45 a.m.	Break Into Working Groups
11:00 a.m.	Working Groups Report Back to Plenary
12:00 noon	LUNCH available in the Refectory
1:00 p.m.	Plenary Session: General Instructions for Final Working Group Sessions *Gregory Choppin, Chair* *Teresa Fryberger, Vice-Chair*
1:30 p.m.	Working Groups Meet for Last Time
3:30 p.m.	Working Groups Report Back to Plenary
4:30 p.m.	Adjourn Open Session
CLOSED SESSION (Committee and NRC Staff ONLY)	
6:00 p.m.	**Committee Dinner (Executive Dining Room)**

Friday, August 25

CLOSED SESSION (Committee and NRC Staff ONLY)—NAS Board Room	
8:30 a.m.	**Commence Meeting**
4:00 p.m.	**Adjourn**

APPENDIX C

SUMMARY OF PREVIOUS REVIEWS OF DOE'S ENVIRONMENTAL QUALITY RESEARCH AND DEVELOPMENT PORTFOLIO

The Department of Energy's (DOE's) Strategic Laboratory Council (SLC) recently conducted an analysis to determine the adequacy of the current portfolio of DOE research and development (R&D) activities to meet the objectives of the Environmental Quality (EQ) business line (DOE, 2000g). After the SLC's analysis was published, the Technology Development and Transfer Committee of DOE's Environmental Management Advisory Board (EMAB) commented on the results of the analysis, evaluated the process used to develop the analysis, and offered recommendations in a letter report (DOE, 2000h).

The major findings and recommendations from the adequacy analyses are summarized below, followed by a table summarizing the identified major EQ R&D gaps and opportunities (Table C.1). The full text of the EMAB letter report is included at the end of this appendix.

ADEQUACY ANALYSIS OF THE ENVIRONMENTAL QUALITY RESEARCH AND DEVELOPMENT PORTFOLIO (DOE, 2000G)

The SLC panel arrived at the following conclusions:

The EQ R&D Portfolio adequately addressed three of the ten technology categories:

- manage mixed low-level and TRU wastes;
- manage spent nuclear fuel; and
- dispose high-level waste, spent nuclear fuel, and nuclear materials.

Three of the ten technology categories were addressed in a moderately adequate manner:

- manage high-level waste;
- manage nuclear material; and
- dispose TRU, low-level, mixed low-level, and hazardous waste.

Four of the ten technology categories were inadequately addressed:

- environmental remediation;
- deactivate and decommission;
- minimize waste generation; and
- long-term stewardship.

The panel considered the magnitude of the gaps for each technology category and how important filling those gaps is to meeting the EQ strategy and objectives. The panel combined these estimates of the significance of these gaps with the adequacy assessment to identify four priority areas for improving the portfolio:

- environmental restoration;
- manage high-level waste;
- deactivate and decommission; and
- long-term stewardship.

The SLC panel developed a number of findings and recommendations on how DOE might improve its EQ R&D portfolio:

Finding 1: The EQ Portfolio has significant gaps and, as a whole, is underinvested.

Recommendation 1: Additional R&D funding is warranted for priority investments. The highest priority areas are: environmental restoration; manage high-level waste; deactivation and decommissioning; and long-term stewardship.

Finding 2: The R&D portfolio does not include a longer-term vision and "strategic" elements such as alternative technologies and next-generation solutions.

Recommendation 2: Part of the R&D portfolio needs to focus on the long-term mission to provide fundamental information that will allow for better understanding and definition of the larger, more difficult problems that will not be solved in the next 5 to 10 years. A portion of the R&D profile should be devoted to strategic R&D, such as "backup" technolo gies in high risk/high budget areas to reduce the programmatic risk to the department.

Finding 3: The funding distribution across the maturity spectrum is unbalanced.

Recommendation 3: The portfolio needs to be more balanced across the technical maturity spectrum without sacrificing recent successes in technology deployment. The maximum benefit from R&D will be obtained through a balanced portfolio that will foster the development of next generation solutions from basic R&D through applied research and development and ultimately to deployment. Basic research should continue to be targeted at a broad spectrum of disciplines that are relevant to the issues facing the EQ business line. Important areas of investment in applied research include separations, robotics, characterization and sensors, and institutional controls related to stewardship.

Finding 4: Significant life-cycle costs and corresponding R&D hinge on highly uncertain end states.

Recommendation 4: DOE must continue to emphasize the development of waste acceptance criteria and definition of end states for both sites and facilities. This includes the need to gather data and develop fundamental knowledge that supports these efforts.

Finding 5: Additional effort is required to identify priorities based on risk.

Recommendation 5a: DOE must develop a better understanding of the risk associated with hazardous materials and develop tools that credibly represent those risks in an open and transparent manner in order to increase the ability to balance human health and environmental risk with other considerations in DOE decision making.

Recommendation 5b: DOE must develop a better understanding of programmatic risks and their potential impact on meeting DOE objectives to improve the long-term management of EQ problems. This supports recommendation 2 on the need for alternative approaches in high risk/high cost areas.

Finding 6: Technology Categories are highly interdependent.

Recommendation 6: Both “Long-Term Stewardship” and “Minimize Waste Generation” categories require additional emphasis and the associated R&D should be applied across the other EQ objectives.

Finding 7: Interfaces among business lines are not adequate to establish fully complementary and synergistic programs.

Recommendation 7a: Interfaces with other DOE business lines and their portfolios should continue to be recognized, developed, and fostered. Synergism and exchange of information should be sought out and acknowledged where appropriate.

Recommendation 7b: Continue to improve the portfolio process so that it will provide a long-term view of the DOE business lines.

TABLE C.1 R&D Gaps and Opportunities Identified by the Strategic Laboratory Council's Adequacy Analysis

Technical Category	Gaps	Opportunities
Environmental Remediation	• Understanding of fate and transport of contaminants in the vadose zone (including improved characterization and modeling of contamination in the vadose zone). • Sensors and characterization technologies particularly for dense non-aqueous liquids (DNAPLs) but also for metal and radioactive contaminants. • Understanding of long-term performance of in-situ containment and stabilization techniques, including caps. • Understanding of natural attenuation and the potential role of monitored natural attenuation as a complement or alternative to active remediation.	• Develop improved understanding and modeling of vadose zone fate and transport processes to support improved risk analysis and remediation and monitoring system designs. • Develop improved sensor technologies for characterization and monitoring to improve understanding and reduce uncertainties in the current nature and extent of contamination and for long-term stewardship applications. • Develop improved understanding of the long-term performance of caps, in-situ containment, and stabilization technologies to reduce the likelihood of failure and re-remediation in the future, and to reduce costs associated with long-term monitoring.
Deactivation & Decommissioning (D&D)	Short-Term Gaps • Robotic/remote systems and their components to improve worker safety, reduce dose, and increase productivity. • Protection of workers in the field from industrial hazards Long-Term Gaps • Real-time characterization and decontamination of volumetrically contaminated materials to recycle and reuse materials within DOE. • Cost-effective and efficient characterization and decontamination of surface-contaminated materials to free-release limits. • Efficient segregation of waste materials to properly	• Reduce the costs anticipated during the D&D of surplus facilities through the deployment of improved technologies in the future. • Leverage progress made in the DOE Robotics and Intelligent Machines Program. • Transfer lessons learned from D&D of facilities into new practices of sustainable construction and facility operations that take into account the full life-cycle costs of construction, operation, dismantlement, and site stewardship during facilities planning. New DOE facilities and utility power plants can more adequately plan for facility decommissioning and waste management during the design phase of the new facilities.

	classify wastes and provide opportunities for recycling. • Improved automation and intelligence of robotics and remote systems to improve safety, efficiency, and productivity. • Integration of robotics and characterization systems to preclude the need to place workers into hostile environments. • Low-cost, remote-operated size reduction and demolition equipment. • Low-cost, integrated surveillance and maintenance systems.	
Manage Mixed Low-Level Waste (MLLW)/ TRU	• Alternatives to incineration for treatment of MLLW. • Long-term research that supports the economical treatment of future sources of MLLW, including, but not limited to, the large volume of disparate wastes from D&D activities	• Reduce the inventory of stored wastes. • Develop alternatives to incineration for treatment of MLLW. • Develop suitable handling/transportation packaging systems that enable intermodal (rail/ truck) transportation options to be employed (short-term opportunity).
Manage High-Level Waste (HLW)	• Retrieval of HLW from difficult (single shell and obstructed) tanks, particularly those with potential leaks and those where the waste is difficult to mobilize. • Treatment process for the balance of the Hanford HLW (Phase II) (e.g., advanced separations techniques for actinides and fission products). • Treatment process for INEEL calcine waste. • Methods to improve tank integrity and leak mitigation, including life extension methods, corrosion studies, tank integrity detection techniques, and barriers for leaks.	• Invest in strategic or longer-term R&D in separations, higher waste loading, and reduced HLW waste form volumes to achieve reductions in life-cycle costs for treatment of HLW. • Develop new generation of technologies, processes, and operating regimes that could significantly reduce costs and technical risks.

Technical Category	Gaps	Opportunities
Manage High-level Waste (HLW)	• Methods to close a tank from which wastes have been retrieved.	
Manage Spent Nuclear Fuel	• Lack of final waste acceptance criteria.	• Develop multi-purpose canisters and improved characterization and monitoring technologies to reduce life-cycle costs and worker exposure.
Manage Nuclear Materials	• Innovative technologies to address unique materials. • Assay technology, gas generation research, moisture measurement, and stabilization process development related to U-233. • Research on hydrogen gas generation.	• Develop innovative safeguards and security technologies to reduce long-term costs for storage and management of nuclear materials. • Strengthen the portfolio through improved integration among DOE offices.
Dispose High-level Waste/Spent Nuclear Fuel and Nuclear Materials	• Need for closure of remaining technical issues with Nuclear Regulatory Commission staff before submittal of license application. • Long-term test data to reduce uncertainty with natural and engineered barrier performance. • Finalization of disposal criteria (after licensing).	• Develop better understanding of natural and engineered environments to improve performance analyses and reduce uncertainty of the performance of the site, which could reduce life-cycle costs by reducing design conservatism.
Dispose of TRU, Low and Mixed Low-Level Waste and Hazardous Materials	• Research to reduce uncertainties in waste system performance. • Capabilities for rapid assessment of technical and performance issues during waste disposal operations.	• Develop of alternative backfill and especially alternative ways to emplace backfill, which could result in significant cost savings. • Develop techniques for emplacement of remote-handled TRU and large packages. • Minimize the generation of TRU, low-level, mixed low-level, and hazardous waste during ongoing DOE operations, which could reduce life-cycle costs of waste disposal. • Improve engineered systems for shallow disposal of MLLW, LLW, and hazardous waste, which could reduce long-term stewardship costs.
Minimize Waste	• Comprehensive inventory of wastes that are being	• Improve design and construction processes to

Generation	generated by new and ongoing DOE activities. • Identification of significant process waste streams (i.e., those that are created during the production of the desired end projects from EM operations and R&D projects).	include pollution prevention criteria and life-cycle impacts, which could minimize the need for shielding wastes, the production of demolition and tank wastes, and allow for the ability to recycle metals. • Apply private sector methodologies to EQ operations. • Apply technologies developed by other DOE offices and other agencies.
Long-Term Stewardship	• Information and data management and dissemination technologies to reliably maintain and ensure that there is an effective means of communicating the history of each site within a stewardship function to future generations. • Research to address the effectiveness of social institutions in maintaining and propagating the institutional systems required for long-term stewardship. • Improved understanding of subsurface and fate and transport processes at remediation sites to assist in the development of the requirements of long-term stewardship. • New capabilities in the area of long-term system performance monitoring and surveillance. • Long-term barrier design, performance testing, and alternatives development to address the varied site configurations and environmental conditions that stewardship will have to address. • Computer models to address risk and cost, and predict system performance to allow effective long-term stewardship option selection and improve the ability to develop better total life-cycle costs. • Cost-effective methods and technologies for maintenance and monitoring of stabilized sites.	

ENVIRONMENTAL MANAGEMENT ADVISORY BOARD TECHNOLOGY DEVELOPMENTANDTRANSFERCOMMITTEE U.S. Department of Energy

October 10, 2000

Dr. David Bodde,
Co-Chair
EM Advisory Board
U.S. Department of Energy
1000 Independence Ave., SW Washington, D.C. 20585

Mr. Joel Bennett,
Co-Chair
EM Advisory Board
U.S. Department of Energy
1000 Independence Ave., SW Washington, D.C. 20585

SUBJECT: Review of the *"Adequacy Analysis of the Environmental Quality Research & Development Portfolio"* (September 2000)

Dear Dr. Bodde and Mr. Bennett:

This letter provides the results of a review of the subject document that was recently conducted by the Technology Development and Transfer (TD&T) Committee of the Environmental Management Advisory Board (EMAB). Mr. Gerald Boyd, Deputy Assistant Secretary, Office of Science and Technology, requested the review.

BACKGROUND

The *Adequacy Analysis* was prepared under the leadership of the Strategic Laboratory Council (SLC) and was released as a final report in September 2000. This SLC effort was co-chaired by Dr. Paul Kearns of the Idaho National Engineering and Environmental Laboratory (INEEL) and Dr. James Helt of Argonne National Laboratory (ANL). The stated purpose of the document was to determine the adequacy of DOE's research & development portfolio in providing the science and technology required to achieve the strategic goals and objectives of DOE's Environmental Quality (EQ) business line.

The document was developed with the participation of people drawn mostly from national laboratories, large EM sites, and DOE's Office of Environmental Management, Office of Science, and Office of Civilian and Radioactive Waste Management. In addition, one representative each from the Environmental Protection Agency and the Department of Defense participated, as well as several persons not affiliated with DOE.

CHARGE TO THE TD&T COMMITTEE

Mr. Boyd's charge to the TD&T Committee for the review involved three aspects:

1. Does the Committee think the process used in developing the document was adequate?
2. What is the Committee's opinion about the results of the analysis?
3. Finally, does the Committee have any recommendations with regard to the analysis?

TD&T REVIEW PROCESS

Members of the TD&T Committee met in Washington, D.C. on October 3–4, 2000. The first day of the review involved a set of interactive discussions with OST's senior management team, Drs. Kearns and Helt of the SLC, and senior technical persons representing various contractors at Hanford, Savannah River, and Idaho, who had either participated in the analysis or were knowledgeable about the results. During the meeting, we also received a progress report from Greg Symmes of the National Research Council (NRC), who is directing a related effort on EM's R&D Portfolio that is underway at NRC.

The Committee appreciated the participation of so many key individuals in this review and benefited greatly from the discussions that took place. Based on the information and views exchanged, Committee members were readily able to address all elements of the charge. The Committee's findings and recommendations related to each element are provided below. An agenda and committee membership list are attached.

FINDINGS AND RECOMMENDATIONS

Charge 1: Adequacy of the process used to develop the analysis.

The impact of future adequacy analyses will be more far-reaching if conducted earlier in the budgetary cycle, and if more time is provided to enable a comprehensive understanding of adequacies and gaps to be developed. All participants in the review agreed that the adequacy analysis had been conducted over a relatively short timeframe. Nevertheless, the Committee found that the process used to develop the results had many positive elements, yielded a useful product that can be built upon in the future, and was generally adequate. We recognized that this was the first time an adequacy analysis of the EQ R&D Portfolio had ever been undertaken by DOE. This, in itself, represents a major step forward. The SLC (and especially Drs. Kearns and Helt) should be commended for taking the leadership on this effort and for arranging the excellent facilitating support from the INEEL, which allowed the participants to work quickly and efficiently.

It was further clear to the Committee that the interactions that had taken place among the various participants during development of the analysis was a very valuable aspect in arriving at the final results. The involvement of a cross-section of EM-savvy individuals from different organizations for an EM corporate purpose proved highly beneficial and yielded additional perspectives that are usually not attained by a top-down or bottom-up analysis of this type.

The final document provides many useful insights and recommendations that can guide a stronger R&D program for EM. Overall, the Committee found that the process directed by the SLC produced a positive document that lends credibility and bolsters the rationale for many parts of the OST program.

Although the Committee believes that the results of the analysis are valuable, the Committee also thinks the process would benefit in the future by including more reviewers not directly responsible for the work being analyzed. The group of participants could be considered to lack full objectivity for the adequacy analysis since many of their organizations conduct the work that was analyzed. While the commitment of the participants to an EM corporate perspective during the analysis was evident and should be congratulated, the Committee noted that the vast majority of the participants are directly linked to DOE, so some could interpret the results as lacking certain independence.

The Committee recognizes that DOE has artificially confined the scope of the EQ business line, and therefore, this limits what the EQ R&D Portfolio can include. Obviously, this was a major constraint to conducting a comprehensive adequacy analysis of the portfolio for the first time. We take this opportunity to reiterate our previously expressed conclusion that DOE needs to broaden the definition of the EQ business line and integrate it with relevant parts of DOE's other business lines.

Charge 2: Opinion on results of the adequacy analysis.

The Committee generally agreed with the results of the overall adequacy analysis, especially the fact that the R&D Portfolio has a short-term focus and lacks a longer-term strategic vision. We agree that the area of Environmental Remediation, which includes the whole myriad of major subsurface issues that remain to be understood, and the area of Managing High Level Waste are the areas that contain the most significant gaps that need to be addressed by the R&D Portfolio. We also agree that the area of Deactivation/Decommissioning supports the major EM objective of Remediating Sites and Facilities but has not yet received adequate attention from the portfolio.

The Committee found that the revised framework for the R&D Portfolio developed by the participants during the adequacy analysis was a significant improvement over the original framework and should be adopted by DOE. The three elements (Cleanup the Legacy, Disposition Wastes and Unneeded Materials, and Manage Future Risk) and five objectives (linked to individual technical categories) that were defined to support the revised framework do a much better job of communicating what the portfolio is all about. The elements also provide an excellent basis for formulating a more compelling message about the contents of the portfolio, developing a better rationale for it, and broadening support.

The Committee also found that defining two new technical categories for the Portfolio (Minimize Waste Generation and Long Term Stewardship) was a very positive outcome. Both of these categories highlight the evolving EQ responsibilities of DOE, especially regarding EM sites. With respect to these two categories, however, the Committee was concerned that the element under which they are found in the revised framework (i.e., Manage Future Risk) could be interpreted more like "Manage Risk in the Future." It is critical that this interpretation not be conveyed because, while both waste minimization and long-term stewardship are more focused on the future, R&D efforts on their behalf need to start now. The message should be that future programmatic risk must be managed starting now. Unfortunately, the Committee could not agree on a crisp re-wording of this element so that the wrong message was not conveyed. This may be worthy of further consideration as the Portfolio is revisited.

Additionally, the Committee is aware of efforts underway within EM (as well as within EMAB) to increase the visibility and impact of efforts involving Environment, Safety, and Occupational Health (ESOH) in the R&D Portfolio. Nevertheless, we noted that ESOH issues were still not sufficiently evident in the results of the current adequacy analysis. Given the current DOE emphasis on this topic, we believe it would be well for EM to consider how relevant ESOH issues are being addressed as part of the EQ R&D Portfolio.

The Committee also considered and discussed individually each of the seven Findings presented in the *Adequacy Analysis.* The first four Findings relate to the R&D Portfolio, while the remaining three relate to operational practices. The Committee spent most of its time considering the Findings involving the R&D Portfolio. Our comments on these four Findings are presented below. For clarity, each Finding is re-stated from the final report before our comments are presented. For the record, the Committee generally concurred with the three Findings on operational practices without significant comment.

"Finding 1: The EQ Portfolio has significant gaps and, as a whole, is underinvested."

Committee comments—While the Committee generally agreed with this Finding, we also found ourselves agreeing that a compelling case for greater investment in the Portfolio still has not been made by EM. Given the scale of the challenge facing EM, we believe that such a case can be made, even considering the lack of definition of such factors as the EM baseline, site end-states, risks, long-term budgets, political support, and appropriate contract incentives. These are realities whose existence needs to be acknowledged but which should not be used as an excuse for failing to support science and technology in EM with sound rationale and planning.

The Committee has been encouraged by the progress we have seen within EM during the past few years regarding science and technology and the new mechanisms that are being put into place. These include the development of roadmaps, development of waste disposition maps, increased use of projectization, and R&D Portfolio planning and analysis. The Committee believes the supporting case for increased R&D investment needs to be made in terms of real payoff to the country. In this context, participants in the EQ R&D Portfolio need to clearly move away from a community entitlement mentality as the basis for receiving increased investment. This means moving from thinking like *"We should receive 'X' percent of the overall budget for R&D purposes."* to a value-added approach that emphasizes something like *"Our R&D efforts will address and resolve these critical public and environmental health, cost, and schedule risks."*

"Finding 2: The R&D portfolio does not include a longer-term vision and 'strategic' elements such as alternative technologies and next-generation solutions."

Committee comments—The Committee agreed with this Finding and believes it is not only a manifestation of the under-investment problem but also of the cultural and financial situation in which EM finds itself, governed by compliance agreements that were formulated independently of current budgetary and technical realities.

Further, the Committee believes that science and technology (S&T) continues to be under appreciated within EM as the source of needed long-term solutions. While this situation has clearly improved during the tenure of Undersecretary Moniz, we are concerned that some of the positive recent impacts and advances we have seen may not become more solidly institutionalized.

"Finding 3: The funding distribution across the technology maturity spectrum is unbalanced."

Committee comments—The bimodal funding distribution, in which DOE's investments in S&T are focused on basic research and demonstration/deployment activities, leaves a gap in applied research and development. The Committee believes that this is another manifestation of under-investment. However, it also reflects EM's reaction to the pressure from Congress to show more deployments (i.e., more payoff from past investments). Further, it indicates that EM has still not developed an integrated S&T program that links basic and applied research seamlessly with development and deployment efforts that address and solve problems in the field.

The Committee is convinced that the imbalance in funding distribution cannot be successfully addressed unless "users" are more effectively involved in the overall S&T process from the beginning. Users in EM have consistently demonstrated that they are willing to co-invest with OST in such programs as the Technology Deployment Initiative (TDI) and Accelerated Site Technology Deployment (ASTD). However, these programs have still not become firmly institutionalized. In addition, DOE has not fully supported adequate funding from Congress for the EM Science Program and has seen funding for this program decline steadily. The current increase in the FY01 budget for OST proposed by Congress is heartening to the Committee. Hopefully, this will provide EM with a further opportunity to move toward a more coherent, integrated, seamless, effective S&T program.

"Finding 4: Significant life-cycle costs and corresponding R&D hinge on highly uncertain end-states."

Committee comments—This Finding appears to be a fact-of-life in the EM world that must be accepted and continually dealt with. Rather than dealing with the often-elusive concept of defining "end-states," which are often decades away, it may be more useful to focus on defining a series of more limited "intermediate-points" or "end-points," the sum total of which can eventually lead to an end-state. We believe that end-points can potentially be better defined, and they lend themselves to better overall management and measurement of progress. More precise terminology may also build more credibility with Congress and assist in making a case for more funding for technology needs.

Charge 3: Recommendations about the adequacy analysis.

The Committee's recommendations regarding the adequacy analysis are presented below.

1. DOE should institutionalize the process of conducting an adequacy analysis of the EQ R&D Portfolio. This effort should become a deliberate and formal process, and adequate time and resources should be allocated for it.

2. EM (OST) should accept the results of the first adequacy analysis and use them in a proactive way to improve its R&D Portfolio.

3. EM should perform an adequacy analysis of its R&D Portfolio at least every two years.

4. The community of participants used to develop an adequacy analysis should be broadened to enhance the credibility and perspective (objectivity) of the Portfolio and the results. The participants should include a limited number of external independent experts.

5. EM still needs to focus on more effective ways to define and support the expected payoff from the OST program. The waste disposition roadmaps developed by the INEEL should be more widely used as the basis for helping to define where OST should be making its S&T investments.

This concludes our comments and recommendations. The Committee very much appreciated the opportunity to conduct this review and offer our views for consideration by EM. We received excellent cooperation from OST management, as well as from the SLC and senior individuals from the DOE contractor community.

We are encouraged by the attention being given to improving the S&T program and look forward to working with EM on the whole range of issues represented by the EQ R&D Portfolio.

Sincerely yours, Edgar Berkey, Ph.D. Chairman Technology Development & Transfer Committee

cc: James Melillo, DOE-EM, EMAB TD&T Committee Members

Attachments [not included in appendix]

APPENDIX D

DESCRIPTIONS OF DOE'S ENVIRONMENTAL QUALITY TECHNICAL CATEGORIES

These descriptions are based largely on those in the Department of Energy's (DOE's) Environmental Quality (EQ) research and development (R&D) portfolio document (DOE, 2000b) and are intended to provide the reader with an overview of the magnitude and duration of DOE's "EQ challenges" (see Sidebar 2.3). They are not intended to represent a comprehensive description of the problem areas or the types of R&D activities currently being conducted by DOE.

MANAGE HIGH-LEVEL WASTE

High-level waste (HLW) is highly radioactive material resulting from reprocessing of spent nuclear fuel, which includes both liquid waste and solid residues. Large quantities of HLW were generated during production of nuclear weapons and reprocessing of defense production reactor fuels. There are 280 large radioactive waste storage tanks and more than 63 smaller underground storage tanks across the DOE complex that contain more than 340,000 cubic meters (90 million gallons) of HLW waste. Most of these tanks have exceeded their design life, some have leaked, and all represent potential occupational and public risks.

The waste is currently stored at five main locations in both solid and liquid form: (1) Savannah River, South Carolina; (2) Hanford, Washington; (3) Idaho National Engineering and Environmental Laboratory (INEEL); (4) Oak Ridge Reservation, Tennessee; and (5) West Valley Demonstration Project, New York. To protect the public and the environment, much of this waste must be retrieved from the tanks and converted into an appropriate form for long-term disposal. Some HLW has been immobilized in glass at Savannah River and West Valley. DOE has signed federal facility agreements with state and federal regulators that drive the scope and schedule for cleanup and closure of the tanks. DOE estimates that HLW cleanup will continue until at least 2046, at a total projected life-cycle cost of $54 billion. In fiscal year 2000, DOE spent approximately $57.6 million on R&D to address needs related to the management of high-level waste. DOE also recognizes that after cleanup most sites that stored HLW will require long-term institutional management measures indefinitely to protect human health and the environment (see “Long-Term Institutional Management” below).

MANAGE MIXED LOW-LEVEL/TRANSURANIC WASTE

Mixed low-level waste (MLLW) is low-level waste that contains both chemically hazardous and radioactive components. Transuranic (TRU) waste is any waste, except for HLW, containing more than 100 nanocuries per gram of long-lived (>20 years), alpha-emitting TRU radionuclides. TRU waste is produced primarily from reprocessing of irradiated fuel and fabrication of nuclear weapons and contains isotopes such as plutonium and americium. Unlike HLW, TRU waste is non-heat bearing. Low-level waste is waste that is not spent fuel, HLW, or uranium or thorium mill tailings.

Thirty-six DOE sites store about 165,000 m^3 of mixed low-level and transuranic waste. Considerable amounts of TRU waste also contain hazardous constituents subject to regulation under the Resources Conservation and Recovery Act (RCRA) or the Toxic Substances Control Act. Since 1970, DOE has placed TRU waste in retrievable storage, such as metal drums or boxes, either on storage pads, in buildings, or in tanks. TRU waste is managed at 21 sites. DOE has begun disposal of stored post-1970 TRU waste at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Because MLLW contains chemically hazardous as well as non-transuranic radioactive materials, it is subject to regulation under both RCRA and the Atomic Energy Act. The storage, treatment, and disposal of MLLW are subject to state and federal regulations. The estimated life-cycle cost for management and disposition of mixed low-level and TRU waste is more than $18 billion. In fiscal year 2000, DOE spent approximately $29.1 million on R&D related to the management of mixed low-level/TRU waste.

MANAGE SPENT NUCLEAR FUEL

Spent nuclear fuel (SNF) is irradiated nuclear fuel that has not been reprocessed. The United States operated 14 nuclear defense production reactors between 1944 and 1988 to produce plutonium and tritium for nuclear warheads. In addition, the United States operated many other test reactors to encourage and support both commercial and military reactor developments. (The spent nuclear fuel arising from the operation of commercial nuclear power plants is described below.) During that time, most of the nuclear fuel rods and targets irradiated in the reactors were reprocessed to extract the plutonium or tritium and the remaining enriched uranium for reuse. In addition, the U.S. Navy operated many nuclear propulsion reactors from which the fuel assemblies were processed to recover and reuse the remaining fissile uranium. DOE's SNF is not categorized as waste, but it is highly radioactive and must be stored in special facilities that shield and cool the material. Most SNF is stored in indoor pools under water, although some spent fuel is kept in dry storage.

Three DOE sites (INEEL, Savannah River, and Hanford) manage most of the SNF in the DOE complex. Hanford has an inventory of over 2,100 metric tons heavy metal (MTHM) of SNF from its production reactors. After washing, packaging, and drying, this SNF will be transferred to dry storage until shipment (either to a repository or to an alternative treatment system). INEEL has an inventory of 270 MTHM of SNF, and expects to receive an additional 60 MTHM. After on-site storage, drying, and packaging, all SNF is expected to be shipped off-site to a repository for disposal. Savannah River has an inventory of 20 MTHM, and expects to receive an additional 30 MTHM from off-site sources. The SNF is expected to be prepared and placed in an off-site geologic repository (the same one as for commercial spent fuel and HLW). The total life-cycle cost for management and preparation for disposal of DOE's SNF is estimated to be about $7 billion (DOE, 2000b). In fiscal year 2000, DOE spent approximately $12 million on R&D related to the management of spent nuclear fuel.

MANAGE NUCLEAR MATERIALS

A major consequence of the end of the Cold War has been a decrease in the number of U.S. nuclear weapons deployed around the world. This decrease resulted in nuclear weapons components being returned to DOE and classified as surplus materials (approximately 200 metric tons of U.S. weapons-usable fissile materials, which includes highly enriched uranium and plutonium, are classified as surplus materials). Disposition of this surplus material will be carried out either by making it into reactor fuel and burning it in electricity-producing commercial reactors (producing spent fuel) or by immobilizing the material mixed with high-level waste. In both cases, the resulting materials will be prepared for disposal in the geological repository.

Other nuclear materials are present in weapons complex facilities that were shut down in the late 1980s and early 1990s due to concerns over safety and environmental problems, and the end of the Cold War.

DOE also has an inventory of over 700,000 metric tons of depleted uranium hexafluoride and a variety of special purpose isotopes like U-233. The estimated life-cycle cost for management and disposition of DOE's nuclear materials is approximately $7 billion (DOE, 2000b). In fiscal year 2000, DOE spent approximately $7.6 million on R&D related to the management of nuclear materials.

DISPOSE OF HIGH-LEVEL RADIOACTIVE WASTES, SPENT NUCLEAR FUELS, AND NUCLEAR MATERIALS

DOE is responsible for providing for the permanent disposal of U.S. high-level radioactive waste and SNF (Public Law 97–425). The Yucca Mountain Site in Nevada has been designated as the only site to be characterized to determine its suitability for a geologic repository (Public Law 100–203). The types of waste that will be disposed of in the geologic repository consist of commercial spent fuel (including mixed oxide spent fuel [i.e., fuel that contains both uranium and plutonium from weapons dismantlement]), high-level waste (including immobilized plutonium), and DOE spent fuel (including naval spent fuel). Other wastes, such as greater-than-class-C, may also be disposed of in the repository.

Commercial spent fuel consists of fuel assemblies discharged from electricity-generating nuclear reactors and is located at 72 nuclear power plant sites and one independent storage site in 33 states. The total inventory of spent fuel at the end of 1998 was estimated to be about 38,000 MTHM, and the expected inventory in 2040 is projected to be about 85,000 MTHM. High-level waste to be disposed of is immobilized (generally as a borosilicate glass or a ceramic) and encased in metal canisters. It is estimated that approximately 22,000 canisters will be produced through 2035 (including those that will contain immobilized surplus weapons-usable plutonium). The DOE spent fuel inventory projected to the year 2035 is estimated to be 2,500 MTHM.

DOE plans to submit a site suitability recommendation for the Yucca Mountain Site to the President in 2001, and if the site is determined to be suitable and approved by both the President and Congress (after presidential approval, the state of Nevada can submit a notice of disapproval that can be overridden by a majority vote of both houses of Congress), to prepare and submit a license application to the U.S. Nuclear Regulatory Commission in 2003 for construction authorization for the repository. To obtain the license, DOE must demonstrate that a repository can be constructed, operated, monitored, and eventually closed without unreasonable risk to the health and safety of workers and the public. The repository schedule calls for initial waste emplacement in 2010, followed by several decades of operation and further decades of monitoring and performance confirmation. In fiscal year 2000, DOE spent approximately $47 million on R&D to address needs related to the disposal of high-level radioactive waste, spent nuclear fuels, and nuclear materials.

ENVIRONMENTAL REMEDIATION OF CONTAMINATED SITES (LANDS AND WATERS)

Environmental remediation involves the removal or stabilization of radioactive and/or hazardous contaminants in soil, fractured bedrock, and groundwater. The primary objectives are to identify, contain, remediate, and remove contamination, and to validate that environmental remediation has achieved the desired end state. Approximately 3 million cubic meters (100 million cubic feet) of solid radioactive and hazardous wastes are buried in the subsurface throughout the DOE complex. The largest contamination challenges are at the INEEL, Oak Ridge, Hanford, Rocky Flats, and Savannah River sites. Contaminants are located in the subsurface both above and below the water table. DOE estimates that 75 million cubic meters (2.6 billion cubic feet) of soil and 1.8 billion cubic meters (475 billion gallons) of groundwater are contaminated and require remediation. Contaminants include hazardous metals such as chromium, mercury, and lead; radioactive laboratory and processing waste; explosive and pyrophoric materials; solvents; and numerous radionuclides. The total life-cycle cost of environmental remediation activities through 2070 is estimated to be greater than $13 billion (DOE, 2000b). In fiscal year 2000, DOE spent approximately $52 million on R&D related environmental remediation of contaminated DOE sites.

DEACTIVATION AND DECOMMISSIONING OF CONTAMINATED FACILITIES

Many of the more than 20,000 DOE facilities that were used to support nuclear weapons production and other activities are contaminated with radioactive materials, hazardous chemicals, asbestos, and lead. To reduce the potential for release of radioactive and hazardous materials to the environment, the risk of industrial safety accidents, and the costs of monitoring and maintaining these facilities, DOE plans to deactivate and decommission (D&D) such facilities. Deactivation is defined as activities to reduce the physical risks and hazards at these facilities, to reduce the costs associated with monitoring and maintenance of these facilities (i.e., facility mortgage), and make these facilities available for potential reuse or eventual decommissioning. Decommissioning is defined as activities associated with decontamination, demolition, and final disposition of the facility and the equipment contained within. The estimated life-cycle cost of D&D

activities for facilities currently under DOE responsibility is $12.5 billion. In fiscal year 2000, DOE spent approximately $12.7 million on R&D to address needs related to the deactivation and decommissioning of contaminated DOE facilities.

LONG-TERM STEWARDSHIP

Of the 144 contaminated sites currently under its control, DOE estimates that fewer than 25 percent will be cleaned up sufficiently to allow unrestricted use. At many sites, radiological and non-radiological hazardous wastes will remain, posing risks to humans and the environment for tens or even hundreds of thousands of years. For these sites, a broad-based, systematic approach that integrates contaminant reduction, contaminant isolation, and stewardship will be required to protect human health and the environment (NRC, 2000a; DOE, 1999a, 2001 b). DOE estimates that it currently spends approximately $64 million annually on long-term stewardship activities, and these costs will increase to nearly $100 million annually by 2050, when all sites are expected to be closed (DOE, 2001 b).

MINIMIZATION OF THE RISK OF NEWLY GENERATED RADIOACTIVE AND HAZARDOUS WASTE

The recent adequacy analysis of the EQ R&D portfolio (DOE, 2000g) recommended that a new category of R&D activities be defined to minimize the risk of newly generated DOE radioactive and hazardous waste. DOE currently has no complex-wide R&D program to minimize the generation of new wastes, although site specific work is in progress to address local waste management programs (DOE, 2000g).

APPENDIX E

DESCRIPTIONS OF RELATED RESEARCH AND DEVELOPMENT PROGRAMS

As part of its information-gathering activities, the committee considered research and development (R&D) programs in other federal agencies, such as the Department of Defense (DOD) and the Environmental Protection Agency (EPA). The committee also considered a number of relevant international R&D programs. Although the committee did not conduct a comprehensive examination of national and international R&D programs, it did identify a number of programs that support R&D relevant to the Department of Energy's (DOE's) Environmental Quality (EQ) mission.

U.S. DEPARTMENT OF DEFENSE

The **Strategic Environmental Research and Development Program** is DOD's environmental R&D program, operated jointly with DOE and EPA, with participation by numerous other federal organizations. The program focuses on cleanup, compliance, conservation, and pollution prevention technologies. The development and application of innovative environmental technologies is intended to reduce costs, environmental risks, and/or the time required to resolve environmental problems in these areas while enhancing safety and health. Equally important, the development and application of innovative pollution prevention technologies serves to reduce or eliminate waste problems before they occur. Examples of research emphases are the areas of site characterization and monitoring, remediation, and risk assessment. The total fiscal year 2001 budget is $59.6 million.

The **Environmental Security Technology Certification Program** demonstrates and validates promising, innovative technologies that target DOD's most urgent environmental needs. These technologies are intended to provide a return on investment through cost savings and improved efficiency. Projects are selected in the areas of cleanup, compliance, pollution prevention, and detection and remediation of unexploded ordinances. Technologies are demonstrated and evaluated at DOD sites and effective and affordable technologies are transferred across DOD.

The **Defense Advanced Research Projects Agency,** the central R&D organization for DOD, manages and directs basic and applied R&D projects, and pursues research and technology where risk and payoff are both high and where success may provide advances for traditional military roles and missions. Its mission is to develop imaginative, innovative, and often high-risk research ideas offering a significant technological impact that will go well beyond the normal evolutionary developmental approaches and to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems.

The **Toxic Biological Interactions program** of the U.S. Air Force Office of Scientific Research supports basic research that endeavors to understand how such toxic agents as heavy metals (chromium and cadmium) and various chemicals that constitute fuels, propellants, and lubricants may interact with biological systems at the subcellular and molecular levels to produce toxic effects. The Air Force also supports studies that explore novel experimental and computational techniques for assessing the potential health risks of these agents.

The **Surface and Interfacial Chemistry Program** of the Army Research Office supports research on the decomposition of hazardous molecules on well-characterized surfaces and in organized media (e.g., micelles, microemulsions, vesicles, and monolayer films) at liquid-liquid and liquid-solid interfaces. The development of new experimental probes of these reactions is also of interest. The most important species are organo-phosphorus, -sulfur, and -nitrogen molecules and reactions of organic functional groups on surfaces and in these organized media. The principle reactions of interest are hydrolysis and oxidation, and catalysis is a strongly desired goal of these studies; however, new concepts are encouraged.

The **Mechanical and Environmental Sciences Division** of the Army Research Office supports basic research related to the remediation and restoration of sites contaminated by Army actions and the use of military training lands. The Army Research Office also supports the Research and Technology Integration Directorate, which integrates scientific research and technology.

The Office of Naval Research sponsors an **Environmental Quality Program** that is aimed at developing technology leading to affordable environmental compliance and pollution prevention. The program supports basic research, applied research, and advanced technology development. Program areas include environmental chemistry (basic research), applied research, and environmental requirements advanced technology. The program focuses on technologies directed toward environmentally sound ships, shore-related facilities, and sediment issues, and specific research interests include sensors and improved cleaning methods.

U.S. ENVIRONMENTAL PROTECTION AGENCY

EPA's R&D is funded primarily through its Office of Research and Development (ORD). ORD conducts leading-edge research and fosters the use of science and technology in fulfilling EPA's mission to protect human health and safeguard the environment. It operates several research laboratories across the country that specialize in specific areas of R&D.

The **National Exposure Research Laboratory,** conducts R&D that leads to improved methods, measurements, and models to assess and predict exposures of humans and ecosystems to harmful pollutants and other conditions in air, water, soil, and food.

The **National Risk Management Research Laboratory** conducts research into ways to prevent and reduce risks from pollution that threaten human health and the environment. The laboratory investigates methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. The goal of this research is to provide solutions to environmental problems by developing and promoting effective environmental technologies; developing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national and community levels.

The **Superfund Innovative Technology Evaluation Program was** established by EPA's Office of Solid Waste and Emergency Response and ORD in response to the 1986 Superfund Amendments and Reauthorization Act, which recognized a need for an alternative or innovative treatment technology research and demonstration program. The program is administered by ORD's National Risk Management Research Laboratory.

The National Center for Environmental Research sponsors environmental research grants under the **Science to Achieve Results Program.** Included are fellowships for graduate environmental study and minority academic institutions fellowships for graduate environmental study.

The **Environmental Technology Verification Program** was instituted to verify the performance of innovative technical solutions to problems that threaten human health or the environment. The program was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. It verifies commercial-ready, private sector technologies through 12 pilots.

The **Subsurface Protection and Remediation Division** of the National Risk Management Research Laboratory conducts research and engages in technical assistance and technology transfer on the chemical, physical and biological structure and processes of the subsurface environment, the biogeochemical interactions in that environment, and fluxes to other environmental media.

The **Waste Research Strategy** covers research necessary to support both the proper management of solid and hazardous wastes and the effective remediation of contaminated waste sites. This research includes methods to improve the assessment of existing environmental risks and to develop more cost-effective ways to reduce those risks. This strategy focuses on the following research areas: contaminated groundwater, contaminated soils and the vadose zone, emissions from waste combustion facilities, and active waste management facilities.

The **National Center for Clean Industrial and Treatment Technologies** is a research consortium dedicated to advancing science, engineering, and pollution prevention, established through a base grant from EPA's Centers Program. Since its establishment, the center has initiated 57 projects involving 51 principal investigators, 57 companies, 33 government and other organizations, and well over 100 students. Targeted industry sectors have included chemical processing, metals, manufacturing, energy, and forest products. Participating disciplines have included environmental, chemical, civil, mechanical, metallurgical and geological engineering; chemistry; biology; social science; business; and forestry.

One of the programs sponsored by EPA's National Center for Environmental Research and Quality Assurance is the **Hazardous Substance Research Centers Program.** The mission of the program is to conduct research to develop and demonstrate new methods to assess and remediate sites contaminated with hazardous substances, improve existing treatment technologies, decrease the production and use of hazardous substances, educate hazardous substance management professionals, and improve community public awareness. The program provides basic and applied research, technology transfer, and training and encourages integrated research projects. The program consists of five multi-university centers, which are located in different regions and focus on different aspects of hazardous substance management. EPA, DOE, DOD, academia, and other federal agencies fund the centers. A description of these centers is found in Sidebar E.1.

DOE's Office of Science and Technology and EPA's Office of Solid Waste recently signed a memorandum of understanding (MOU) to improve cooperation on the development of technical solutions to problems associated with mixed wastes. The main objective of the MOU is to provide the Office of Solid Waste with performance and cost data from the demonstration and field testing of mixed waste treatment and control technologies, which is expected to help EPA develop sound and cost-effective regulations and standards for mixed wastes. The effort also is intended to facilitate cooperation in budgetary planning for OST's R&D efforts and EPA's regulatory activities.

U.S. NUCLEAR REGULATORY COMMISSION

The U.S. Nuclear Regulatory Commission's Radiation Protection, Environmental Risk and Waste Management Branch develops, plans, and manages research programs related to the movement of radionuclides in the environment and consequent dose and health effects to the public and workers as a result of nuclear power plant operation, facility decommissioning, cleanup of contaminated sites, and disposal of radioactive waste.

U.S. GEOLOGICAL SURVEY

The **Toxic Substances Hydrology Program** provides scientific information needed to improve characterization and management of contaminated sites, to protect human and environmental health, and to reduce potential future contamination problems. The goal of the program is to provide scientific information on the behavior of toxic substances in hydrologic environments, including surface water, groundwater, soil, sediment, and the atmosphere.

SIDEBAR E.1 EPA'S HAZARDOUS SUBSTANCE RESEARCH CENTERS

The **Great Lakes and Mid-Atlantic Center** focuses on remediation of hazardous organic compounds found in soil and groundwater. Ongoing research focuses on in situ bioremediation, surfactant introduction, and bioventing technologies. The lead institution is the University of Michigan, and other participating universities include Howard University and Michigan State University.

The **Great Plains/Rocky Mountain Center** focuses on contaminated soils and mining wastes. Research covers soil, water, and groundwater contaminated with heavy metals, and organics; wood preservatives in groundwater; pesticides; improved methods for analyzing contaminated soil; and pollution prevention technologies. The lead institution is Kansas State University, and other participating universities include Haskell Indian Nations University, Kansas State University, Lincoln University, and Montana State University.

The **Northeast Center** focuses on incineration/thermal treatment, characterization and monitoring, in situ remediation, and ex situ treatment of industrial wastes. The center is a consortium of 7 universities: the New Jersey Institute of technology (which serves as the lead institution), the Massachusetts Institute of Technology, Princeton, Rutgers, Stevens Institute of Technology; Tufts; and the University of Medicine and Dentistry of New Jersey.

The **South and Southwest Center** focuses on contaminated sediments, in particular, in situ chemical mobilization in beds and confined disposal facilities, in situ remediation, and in situ detection covers. The lead institution is Louisiana State University, and other participating universities include Georgia Institute of Technology and Rice University.

The **Western Region Center** focuses on groundwater cleanup and site remediation with a strong emphasis on biological approaches. Projects address chlorinated solvents; halogenated aromatics (pentachlorophenol and PCBs), nonhalogenated aromatics, including petroleum derivatives; ordinance wastes, heavy metals; and transport and fate. The lead institution is Stanford University, with Oregon State University participating.

The **National Water-Quality Assessment Program** is designed to describe the status and trends in the quality of ground- and surface-water resources and to provide a sound understanding of the natural and human factors that affect the quality of these resources. Regional and national syntheses of information provide summaries on volatile organic compounds, trace elements, and surface water-quality monitoring.

The **Ground-Water Resources Program** encompasses regional studies of groundwater systems, multidisciplinary studies of critical groundwater issues, access to groundwater data, and research and methods development. The program provides unbiased scientific information and many of the tools that are used by federal, state, and local management and regulatory agencies to make important decisions about groundwater resources.

The **Biomonitoring of Environmental Status and Trends** evaluates environmental contaminants and their effects on species and lands under the stewardship of the Department of Interior to provide scientific information and guide management actions. The program is designed to identify and understand the effects of environmental contaminants on biological resources, particularly those resources under the stewardship of the Department of the Interior. The program provides sound scientific information to be used proactively to prevent or limit contaminant-related effects on biological resources. The primary goals are to (1) determine the status and trends of environmental contaminants and their effects on biological resources; (2) identify, assess, and predict the effects of contaminants on ecosystems and biological populations; and (3) provide summary information in a timely manner to managers and the public for guiding conservation efforts. To address these goals, the program will use different approaches, involving a combination of field biomonitoring methods and information assessment tools, for examining contaminant issues at the national, regional, and local levels.

In addition, the U.S. Geological Survey has MOUs with a number of federal agencies. For example, an MOU with the U.S. Nuclear Regulatory Commission explored R&D in the earth sciences related to the management, disposal, and environmental remediation of nuclear and mixed wastes; site decommissioning reviews; uranium in situ mining; and uranium mill tailings at existing and future sites in the United States. An MOU with EPA addressed activities related to the protection of groundwater quality.

NATIONAL SCIENCE FOUNDATION

The **Division of Environmental Biology** supports fundamental research on the origins, functions, relationships, interactions, and evolutionary history of populations, species, communities, and ecosystems. The division also supports a network of long-term ecological research sites, doctoral dissertation research, and research conferences and workshops. Funding for fiscal year 2000 was $89.8 million.

Basic research in the **Directorate for Geosciences** advances scientific knowledge of Earth's environment, including resources such as water, energy, minerals, and biological diversity. The funding level for earth sciences was $102 million for fiscal year 2000. The directorate also supports the **Biocomplexity in the Environment Program,** a set of coordinated activities in environmental science, engineering, and education, which advance scientific knowledge about the connection between the living and non-living Earth system. The Directorate of Geosciences will provide $39.50 million in fiscal year 2001 for focused biocomplexity studies, which will enable the initiation and/or enhancement of several interdisciplinary activities.

The **Environmental Engineering Program** in the Division of Bioengineering and Environmental Systems supports sustainable development research with the goal of applying engineering principles to reduce adverse effects of solid, liquid, and gaseous discharges into land, fresh and ocean waters, and air that result from human activity and impair the value of those resources. This program also supports research on innovative biological, chemical, and physical processes used alone or as components or engineered systems to restore the usefulness of polluted land, water, and air resources. Research may be directed toward improving the cost-effectiveness of pollution avoidance and developing fresh principles for pollution avoidance technologies.

The **Division of Chemical and Transport Systems** supports research that involves the development of fundamental engineering principles, process control and optimization strategies, mathematical models, and experimental techniques, with an emphasis on projects that have the potential for innovation and broad application in such areas as the environment, materials, and chemical processing. Special emphasis is on environmentally benign chemical and material processing. Research support is available in through the following activities: chemical reaction processes; interfacial, transport, and separation processes; fluid and particle processes; and thermal systems. Funding for fiscal year 2000 was $44.3 million.

The **Division of Civil and Mechanical Systems** funds research that contributes to the knowledge base and intellectual growth in the areas of infrastructure construction and management, geotechnology, structures, dynamics and control, mechanics, and materials; sensing for civil and mechanical systems; and the reduction of risks induced by earthquakes and other natural and technological hazards. The division encourages cross-disciplinary partnerships. These partnerships promote discoveries using technologies such as autoadaptive systems, nanotechnology, and simulation to enable revolutionary advances in civil and mechanical systems. Funding for fiscal year 2000 was $48.2 million.

The **Inorganic, Bioinorganic, and Organometallic Chemistry Program** in the Chemistry Division supports research on synthesis, structure, and reaction mechanisms of molecules containing metals, metalloids, and nonmetals encompassing the entire periodic table of the elements. Included are studies of stoichiometric and homogeneous catalytic chemical reaction; bioinorganic and organometallic reagents and reaction; and the synthesis of new inorganic substances with predictable chemical, physical, and biological properties. Such research provides the basis for understanding the function of metal ions in biological systems, for understanding the synthesis of new inorganic materials and new industrial catalysts, and for systematic understanding of the chemistry of most of the elements in the environment.

The **Organic Chemical Dynamics Program** also in the Chemistry Division supports research on the structures and reaction dynamics of carbon-based molecules, metallo-organic systems, and organized molecular assemblies. Research includes studies of reactivity, reaction mechanisms, and reactive intermediates, and characterization and investigation of new organic materials. Such research provides the basis for understanding and modeling biological processes and for developing new or improved theories relating chemical structures and properties. Funding for the Chemistry Division was $139 million for fiscal year 2000.

NATIONAL INSTITUTES OF HEALTH

The **Superfund Basic Research Program** is focused on acquiring new scientific and engineering knowledge that advances both society’s understanding of the human and ecological risks from hazardous substances and the development of new environmental technologies for the cleanup of Superfund sites. The knowledge acquired in this program not only serves as the basis for subsequent basic or applied research in these areas but also provides a foundation for such practical benefits as lower cleanup costs on hazardous waste sites and improvements in human and ecological health risk assessment. The program, created and administered by the National Institute of Environmental Health Sciences, receives funding from EPA through an interagency agreement using Superfund trust monies. The research efforts undertaken by this program complement activities in EPA and the Agency for Toxic Substances and Disease Registry.

NON-FEDERAL U.S. R&D

The Electric Power Research Institute **Decommissioning Technology Program** assists utilities to minimize the cost of decommissioning through enhanced planning, determining optimum financial fund set-aside, applying lessons learned by other utilities with retired plants, and use of advanced technology. For decommissioned power plants, site characterization and final site survey have also been costly elements of their decommissioning activities. Several technical areas have been identified where improved technology could be of considerable benefit to utilities with shutdown plants by reducing labor costs, personnel exposures, and radioactive waste. Chemical decontamination developments are discussed below. Other topics under study include site characterization, fuel pool cleanup, concrete decontamination and other remediation techniques. In conjunction with the Federal Energy Technology Center, evaluation of the applicability to U.S. power plants of technology developed in DOE programs and those in other countries is being carried out, including status reports on appropriate techniques. The Strategic Science and Technology Program addresses priority needs and opportunities by integrating scientific developments and emerging technologies with strategic industry issues and the public good.

INTERNATIONAL R&D PROGRAMS

The committee also considered a number of international programs that support R&D related to DOE's EQ mission. They cover a wide range of issues, such as chemical processes, soil remediation, hydrology, and migration of radionuclides. Some of these programs are described below.

The **Belgian Nuclear Research Centre** is a federal organization for scientific research in the field of safe and peaceful applications of nuclear energy for industrial and medical use.

Atomic Energy of Canada Limited is a leading vendor of nuclear power reactors, engages in a wide range of R&D activities, and provides nuclear engineering products and services worldwide to customers in nuclear and related industries.

The **National Cooperative for the Disposal of Radioactive Waste (Nagra)** in Switzerland provides the technical and scientific basis for safe management of radioactive waste. Nagra has a number of cooperative agreements with other countries, including the United States.

The **Paul Scherrer Institut** in Switzerland is the federal institute for reactor and nuclear R&D. It covers the areas of incineration of wastes; modeling of radionuclide migration through heterogeneous geologic media; chemical behavior of radionuclides during migration; transport of radionuclides through the biosphere; natural analogue studies; hydrological studies; sorption constants on different rocks; immobilization of low-level waste and intermediate-level waste in cement; leaching rates on low-level and intermediate-level waste forms; and long-term corrosion tests on waste-packaging materials.

Nirex, in the United Kingdom, examines safety, environmental, and economic aspects of deep geological disposal. It deals with intermediate-level waste, which accounts for the majority of radioactive waste currently in storage, and with some low-level waste.

The Canadian National Research Council's **Institute for Chemical Process and Environmental Technology** funds research in the following areas: environmental management; chemical sensors; soil remediation, computational fluid dynamics and reactive flow modeling; and chemical process simulation, design, and economics. Chemical process simulation techniques are being investigated as tools for improving process design and developing clean technology for pollution prevention and waste reduction.

The **Geological Survey of Canada** funds research in environmental geology, such as the distribution and concentration of heavy metals near mines, in its Terrain Sciences Division.

The **Environmental Agency of England and Wales** sponsors research in several areas, including waste management. Research projects cover such topics as the effects of substances in groundwater on the migration of radionuclides, national recovery and recycling database for waste management, life-cycle cost of waste management options, radionuclide migration processes in geological media, and environmental impact of old landfills.

APPENDIX F

ANNOTATED BIBLIOGRAPHY OF SELECTED RECENT NATIONAL RESEARCH COUNCIL REPORTS

NUCLEAR WASTES: TECHNOLOGIES FOR SEPARATIONS AND TRANSMUTATION (NRC, 1995)

This report describes the state of the art in separations and transmutation technologies, and considers their application to U.S. high-level radioactive waste and spent nuclear fuel. It concludes that a modestly funded research and development (R&D) program in particular technical areas is of value, but that R&D work is not sufficiently viable to justify delays in geological repository development at Yucca Mountain.

THE WASTE ISOLATION PILOT PLANT: A POTENTIAL SOLUTION FOR THE DISPOSAL OF TRANSURANIC WASTE (NRC, 1996A)

This report addresses the suitability of the Waste Isolation Pilot Plant (WIPP) as a geological repository for transuranic waste by examining scenarios for the possible release of radionuclides to the environment after the repository is filled and sealed. The committee's conclusions were that (1) human exposure to radionuclide releases from WIPP is likely to be low compared to U.S. and international standards and (2) if the repository were sealed effectively and undisturbed by human activity, there would be no credible or probable scenarios for release of radionuclides to the environment. The committee also made several recommendations for additional work that should be done by the Department of Energy (DOE) and its contractors to assess the likelihood of future human disturbance to the repository and to reduce the impacts of such disturbances if they occur. This report (and earlier reports by the same committee) was instrumental in DOE's efforts to gain regulatory approval to open the first U.S. geological repository. The Environmental Protection Agency also used the report in its review of DOE's license application. The WIPP repository received its first shipment of waste in early 1999.

THE HANFORD TANKS: ENVIRONMENTAL IMPACTS AND POLICY CHOICES (NRC, 1996B)

This report reviews a draft environmental impact statement for the remediation of high-level radioactive waste in tanks at the Hanford Site, Washington. The report recommends that remediation activities use a phased decision strategy, proceeding with current cleanup operations while filling in important information gaps before making a final decision as to which technologies and methodologies will ultimately be implemented. Remediation of the tanks should be consistent with plans for the entire Hanford Site, including the environment and future land use.

BUILDING AN EFFECTIVE ENVIRONMENTAL MANAGEMENT SCIENCE PROGRAM: FINAL ASSESSMENT (NRC, 1997)

This report summarizes the potential value of basic research to DOE's cleanup mission and advises DOE on the structure and management of its Environmental Management Science Program (EMSP). The reports includes the following recommendations to improve the program: (1) develop a science plan for the program; (2) examine the entire review process for the EMSP with the goal of increasing its transparency and technical credibility; (3) find a solution to the problem of not being able to "forward fund" projects at national laboratories, and fully fund all awards in the first year; (4) establish an EMSP program director responsible for management of the program who reports directly to the Under Secretary of Energy; (5) convene an independent review panel to review the performance and effectiveness of the program; and (6) convene annual workshops, seminars, and symposia to help facilitate information flow and stimulate new research ideas.

PEER REVIEW IN ENVIRONMENTAL TECHNOLOGY DEVELOPMENT PROGRAMS: THE DEPARTMENT OF ENERGY'S OFFICE OF SCIENCE AND TECHNOLOGY (NRC, 1998)

This report provides an overview of an effective peer review program and its use in R&D decision making. In particular, the report focuses on how peer review can be used to evaluate the technical merit of environmental remediation technologies at various stages of development from basic research through demonstration to deployment. The report includes recommendations on how the Office of Science and Technology (OST) in DOE's Office of Environmental Management (EM) could improve its peer review process, and the linkage of peer reviews to its decision-making processes.

DECISION MAKING IN THE U.S. DEPARTMENT OF ENERGY'S ENVIRONMENTAL MANAGEMENT OFFICE OF SCIENCE AND TECHNOLOGY (NRC, 1999A)

This report examines the prioritization and decision-making processes of DOE-EM's OST. The committee found that OST's decision process is closely linked with the DOE-EM organizational structure, institutional procedures, and program management. The committee framed its major recommendations around the four decision process issues raised in the study charter: appropriateness and effectiveness of OST's decision-making process, appropriate technical factors and the adequacy with which they can be measured, role and importance of effective reviews, and program challenges and measures of success. Specific recommendations include (1) OST should use the best available information on DOE-EM site technology needs as a guide for tailoring program goals; (2) the decision process should be structured using quantifiable attributes wherever applicable but also should allow for managerial flexibility; (3) OST should use the minimum number of stages and gates needed to track a project and should use peer reviews; and (4) the gate reviews of stage-and-gate tracking system should also assess estimations of cost, risk, and schedule.

GROUNDWATER AND SOIL CLEANUP: IMPROVING MANAGEMENT OF PERSISTENT CONTAMINANTS (NRC, 1999B)

This report advises DOE on technologies and strategies for cleaning up three types of contaminants in groundwater and soil: (1) metals, (2) radionuclides, and (3) dense nonaqueous-phase liquids (DNAPLs), such as solvents used in manufacturing nuclear weapons components. Metals and DNAPLs are common not only in the weapons complex but also at contaminated sites nationwide owned by other federal agencies and private companies. They have proven especially challenging to clean up, not just for DOE but also for others responsible for contaminated sites. The report makes a number of recommendations, including the following: (1) in situ remediation should receive a higher priority in the Subsurface Contaminants Focus Area (SCFA); (2) SCFA should work more closely with technology end users in setting its overall program direction; (3) SCFA should sponsor more field demonstrations; and (4) DOE managers should reassess the priority of subsurface cleanup relative to other problems and, if the risk is sufficiently high, they should increase remediation technology development funding accordingly. Although the recommendations are designed for DOE, the bulk of the report will be useful to anyone involved in the cleanup of contaminated sites. The report also contains reviews of regulations applicable to contaminated sites, the state of the art in remediation technology development, and obstacles to technology development that apply well beyond sites in the DOE weapons complex.

AN END STATE METHODOLOGY FOR IDENTIFYING TECHNOLOGY NEEDS FOR ENVIRONMENTAL MANAGEMENT, WITH AN EXAMPLE FROM THE HANFORD SITE TANKS (NRC, 1999C)

While DOE has a process based on stakeholder participation for screening and formulating technology needs, it lacks transparency (in terms of being apparent to all concerned decision makers and other interested parties) and a systematic basis (in terms of identifying end states for the contaminants and developing pathways to these states from the present conditions). The primary purpose of this study is to describe an approach for identifying technology development needs that is both systematic and transparent to enhance the cleanup and remediation of the tank contents and their sites. The committee believes that the recommended end-state-based approach can be applied to DOE waste management in general, not just to waste in tanks. The approach is illustrated with an example based on the tanks at the DOE Hanford Site in Washington state, the location of some 60 percent (by volume) of the tank waste residues.

ALTERNATIVE HIGH-LEVEL WASTE TREATMENTS AT THE IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY (NRC, 1999D)

This report assesses the technical alternatives to calcining of high-level waste (HLW) at the Idaho National Engineering and Environmental Laboratory (INEEL). The calcination process injected waste into a fluidized bed at elevated temperatures to evaporate the water and decompose other material into calcine, a granular ceramic. The calcine was sent to storage in partially buried stainless steel bins enclosed by a concrete vault. As tanks were emptied of HLW, they were used to store liquid waste. The liquid is mixed transuranic (TRU) waste high in sodium, referred to as sodium-bearing waste (SBW). Some of the SBW has been calcined, and for several decades, R&D activities at INEEL have studied technical alternatives for the future remediation, storage, and ultimate disposition of HLW calcine and SBW. The committee concluded that the interim storage of calcine in the bins should be maintained until it becomes clear (1) where the material can be sent, (2) what disposal form(s) are acceptable, and (3) that an approved transportation pathway to a disposal site is available. The committee also concluded that DOE should solidify the SBW as soon as practicable and recommends that solidification options other than calcination be identified. The committee also concluded that a major consideration in deciding how (and whether) to process any radioactive waste for long-term conditioning is that of the risks being added and/or mitigated.

LONG-TERM INSTITUTIONAL MANAGEMENT OF U.S. DEPARTMENT OF ENERGY LEGACY WASTE SITES (NRC, 2000A)

This study examines the capabilities and limitations of the scientific, technical, and human and institutional systems that compose the measures that DOE expects to put into place at potentially hazardous, residually contaminated sites. The committee found that, at a minimum, DOE should plan for site disposition and stewardship much more systematically than it has to date. At many sites, future risks from residual wastes cannot be predicted with any confidence, because numerous underlying factors that influence the character, extent, and severity of long-term risks are not well understood. Among these factors are the long-term behavior of wastes in the environment, the long-term performance of engineered systems designed to contain wastes, the reliability of institutional controls and other stewardship measures, and the distribution and resource needs of future human populations.

RESEARCH NEEDS IN SUBSURFACE SCIENCE: U.S. DEPARTMENT OF ENERGY'S ENVIRONMENTAL MANAGEMENT SCIENCE PROGRAM (NRC, 2000C)

The report provides an overview of the subsurface contamination problems across the DOE complex and shows by examples from the six largest DOE sites (Hanford Site, Idaho Engineering and Environmental Laboratory, Nevada Test Site, Oak Ridge Reservation, Rocky Flats Environmental Technology Site, and Savannah River Site) how advances in scientific and engineering knowledge can improve the effectiveness of the cleanup effort. The committee analyzed the current EMSP portfolio of subsurface research projects to assess the extent to which the program is focused on DOE's contamination problems. The committee also reviewed related research programs in other DOE offices and other federal agencies to determine the extent to which they are focused on DOE's subsurface contamination problems. On the basis of these analyses, the report identifies the highly significant subsurface contamination knowledge gaps and research needs that the EMSP must address if the DOE cleanup program is to succeed. The committee recommends that the subsurface component of the EMSP have the following four research emphases: (1) location and characterization of subsurface contaminants and characterization of the subsurface, (2) conceptual modeling, (3) containment and stabilization, and (4) monitoring and validation.

LONG-TERM RESEARCH NEEDS ON RADIOACTIVE HIGH-LEVEL WASTE AT DEPARTMENT OF ENERGY SITES: INTERIM REPORT (NRC, 2000D)

The committee was asked to provide this interim report to help the EMSP develop a request for proposals (RFP) aimed at HLW management for fiscal year 2001. The committee identified broad research areas that would benefit from a basic science plan and concluded that the RFP should solicit research projects in the following four fields, in order of importance: (1) long-term issues related to tank closure and characterization of surrounding areas; (2) high-efficiency, high throughput separation methods that would reduce HLW program costs over the next few decades; (3) robust, high-loading, immobilization methods and materials that could provide enhancements or alternatives to current immobilization strategies; and (4) innovative methods to achieve real-time and, when practical, in situ characterization data for HLW and process streams that would be useful for all phases of the waste management program. The committee also provided recommendations on several programmatic issues: (1) EMSP should promote "needs driven" or "mission-directed" basic science supporting research on fundamental processes and phenomena with potential high-impact results; (2) EMSP should promote underlying science and technology parallel to baseline or programmatic approaches to enable HLW management efforts to be flexible in dealing with any unanticipated difficulties; and (3) EMSP investigators should interact with problem holders at the sites to learn about the nature of the problems to be solved. The committee plans to produce a final report with more detailed findings and recommendations in the summer of 2001.

LONG-TERM RESEARCH NEEDS FOR DEACTIVATION AND DECOMMISSIONING AT DEPARTMENT OF ENERGY SITES: INTERIM REPORT (NRC, 2000E)

The committee was asked to provide an interim report that addressed the technical content of a fiscal year 2001 EMSP call for research proposals and made recommendations on the areas of research where the EMSP could make significant contributions to solving deactivation and decommissioning (D&D) problems and adding to general scientific knowledge. The committee identified three areas where EMSP-funded research could make significant contributions: characterization, decontamination, and remote systems. Within these areas, it made five recommendations: (1) basic research toward identification and development of real-time minimally invasive and field-usable means to locate and quantify difficult contaminants significant to D&D; (2) basic research that could lead to the development of biotechnological sensors to detect contaminants of interest; (3) basic research toward fundamental understanding of the interactions of important contaminants with the primary materials of interest in D&D projects; (4) basic research on biotechnological means to remove or remediate contaminants of interest from surfaces within porous materials; and (5) basic research toward creating intelligent remote systems that can adapt to a variety of tasks and be readily assembled from standardized modules. The committee also provided DOE with the following general advice on EMSP strategic planning: (1) avoid focusing too narrowly on site-specific problems; (2) develop a more comprehensive, coordinated, and specific definition of complex-wide D&D needs; (3) allow DOE contractors and Site Technology Coordinating Groups to contribute more toward identifying true R&D opportunities; (4) help develop a scientific basis for setting standards for the end states of D&D; and (5) consider further interdisciplinary collaborations among relevant disciplines. The committee plans to produce a final report in the spring of 2001, which will provide more detail on the recommendations and advice in the interim report.

ALTERNATIVES FOR HIGH-LEVEL WASTE SALT PROCESSING AT THE SAVANNAH RIVER SITE (NRC, 2000F)

The original process developed to accomplish the processing of high-level radioactive waste salt solutions stored at the Savannah River Site was in-tank precipitation (ITP), which encountered unexpected problems. A primary alternative selected by the Savannah River Site was a variation of ITP, known as small tank precipitation using sodium tetraphenylborate (TPB) and a backup option, crystalline silicotitanate (CST) ion exchange process. Other options, eliminated by the Savannah River Site, include caustic side solvent extraction and direct grout. This report reviews both the selection process of the two primary alternatives, and the processing options themselves. The committee found that there are potential barriers to implementation of all the alternative processing options and recommends that the Savannah River Site proceed with a carefully planned and managed R&D program for three of the four alternative processing options (small tank precipitation using TPB, CST ion exchange, and caustic side solvent extraction) until enough information is available to make a more defensible and transparent downselection decision.

NATURAL ATTENTUATION FOR GROUNDWATER REMEDIATION (NRC, 2000H)

The term “natural attenuation” refers to the use of unenhanced natural processes for site remediation. The biological, chemical, and physical processes, such as biodegradation, take place in the subsurface and may transform contaminants to less harmful forms or immobilize them to reduce risks. This report takes a look at public concerns about natural attenuation, the scientific bases for natural attenuation, and the criteria for evaluating the potential success or failure of natural attenuation. The principal findings of the report are that natural attenuation is an established remedy for only a few types of contaminants, that rigorous protocols are needed to ensure that natural attenuation potential is analyzed properly, and that natural attenuation should be accepted as a formal remedy for contamination only when the processes are documented to be working and are sustainable. Where communities are affected by contamination, community members must be provided with documentation of these processes and given an opportunity to participate in decision making.

IMPROVING OPERATIONS AND LONG-TERM SAFETY OF THE WASTE ISOLATION PILOT PLANT: INTERIM REPORT (NRC, 2000I)

This committee was asked to advise DOE on the operation of the WIPP and to provide recommendations on two issues: (1) a research agenda to enhance confidence in the long-term performance of WIPP and (2) increasing the throughput, efficiency, and cost-benefit without compromising safety of the national transuranic (TRU) program for characterizing, certifying, packaging, and shipping waste to WIPP. This interim report provides DOE with recommendations on research to enhance confidence in long-term repository performance and improvements to the national TRU program. The committee recommended that DOE develop and implement a plan to sample oil-field brines, petroleum, and solids associated with current hydrocarbon production to assess the magnitude and variability of naturally occurring radioactive material in the vicinity of the WIPP site; eliminate self-imposed waste characterization requirements that lack a legal or safety basis; derive a more realistic gas generation model; consider cost-effective ways to improve the reliability and ease of use of the Transportation Tracking and Communication System; and develop tools for maintaining information needed to respond to a WIPP transportation accident.

DISPOSITION OF HIGH-LEVEL WASTE AND SPENT NUCLEAR FUEL: THE CONTINUING SOCIETAL AND TECHNICAL CHALLENGES (NRC, 2001)

The concept of geological disposal is not new, yet many national programs have been faced with significant challenges siting a geological repository and emplacing spent nuclear fuel and HLW in it. This study, authored by a committee of experts from seven countries, addresses some of the challenges that national programs have confronted or are currently dealing with. The committee concluded that focused attention by world leaders is needed to address the substantial challenges posed by disposal of spent nuclear fuel and HLW. In addition, the biggest challenges in achieving safe and secure storage and permanent waste disposal are societal. Technically, there are only two feasible options: (1) storage on or near the Earth’s surface and (2) placement in deep underground repositories. After four decades of study, the geological repository option remains the only scientifically credible, long-term solution for safely isolating waste without having the rely on active management. Furthermore, although there are still some significant technical challenges, the broad consensus within the scientific and technical commu nities is that enough is known for countries to move forward with geological disposal. This approach is sound as long as it involves a step-by-step, reversible decision-making process that takes advantage of technological advances and public participation.

APPENDIX G

LIST OF ACRONYMS AND ABBREVIATIONS

AAAS	American Association for the Advancement of Science
BER	Office of Biological and Environmental Research (DOE)
BES	Office of Basic Energy Sciences (DOE)
COSEPUP	Committee on Science, Engineering, and Public Policy (National Academies)
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
D&D	Deactivation and Decommissioning
DOD	Department of Defense
DOE	U.S. Department of Energy
EM	Office of Environmental Management (DOE)
EMAB	Environmental Management Advisory Board (DOE)
EMSP	Environmental Management Science Program (DOE)
EPA	U.S. Environmental Protection Agency
EQ	environmental quality
EMAB	Environmental Management Advisory Board
ERPS	Environmental Restoration Priority System
GAO	U.S. General Accounting Office
HLW	high-level waste
INEEL	Idaho National Engineering and Environmental Laboratory
IRI	Industrial Research Institute
LLW	low-level waste
MOU	memorandum of understanding
MD	Office of Fissile Materials Disposition (DOE)
MTHM	metric tons heavy metal
MLLW	mixed low-level waste
NE	Office of Nuclear Energy, Science and Technology (DOE)
NERAC	Nuclear Energy Research Advisory Committee
NERI	Nuclear Energy Research Initiative

NRC	National Research Council
NSF	National Science Foundation
NWTRB	Nuclear Waste Technical Review Board
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology (DOE-EM)
OTA	Office of Technology Assessment
R&D	research and development
RCRA	Resources Conservation Recovery Act
RFP	request for proposals
RW	Office of Civilian Radioactive Waste Management (DOE)
SBW	sodium-bearing waste
SERDP	Strategic Environmental Research and Development Program (DOD)
SC	Office of Science (DOE)
SCFA	Subsurface Contaminants Focus Area
SLC	Strategic Laboratory Council
SNF	spent nuclear fuel
TD&T	Technology Development and Transfer
TRU	transuranic waste
TSCA	Toxic Substances Control Act
USNRC	U.S. Nuclear Regulatory Commission
WAG	Washington Advisory Group
WIPP	Waste Isolation Pilot Plant
WPRS	Work Package Ranking System