DOE Research and Development Portfolio

Environmental Quality

Volume 2 of 4 / February 2000

U.S. Department of Energy

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

DOE Research and Development Portfolio

Environmental Quality

Volume 2 of 4

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Washington, DC 20585

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To meet the Department of Energy's commitments to the American public, our investments in Environmental Quality are focused on advancing our scientific understanding and providing new technology to aggressively clean up the environmental legacy of our nuclear weapons programs, minimize future waste generation, safely manage nuclear materials, and permanently dispose of the nation's radioactive waste.

Over the past two years, the Department has undertaken a major effort to ensure that our research and development programs are balanced and that our Federal investments are appropriately aligned with the needs of the nation. To do this, we have instituted a new portfolio approach to managing our research and development activities. This provides, for the first time, a clear single-source description of the Department's entire research portfolio of over $7 billion. Attached is DOE's Environmental Quality R&D Portfolio, Volume II of the Department's five-volume research and development portfolio.

This document is intended to help: (1) describe our current research and development activities and showcase our recent accomplishments; (2) increase the impact of our science and technology investments in terms of reduced cost, improved safety, and enhanced cleanup; (3) make investment decisions that ensure the Department can meet its regulatory commitments; and (4) improve our planning to achieve the portfolio balance needed to meet the nation's long-term needs.

The investments presented in the Environmental Quality R&D Portfolio are an absolutely essential, albeit relatively small, part of the Department's total investment in research and development. These investments have already provided, and will continue to provide, the scientific knowledge and new technologies necessary to meet the Department's regulatory commitments and reduce the cost of the complex-wide cleanup effort. In addition, these investments provide a small, but vital, seed corn in helping the country achieve sustainable development while improving environmental quality. It is our hope that this document communicates both the basis for these investments as well as the highly focused approach we are taking to solve some of the nation's most technically challenging, intractable environmental problems.

Ernest J. Moniz
Under Secretary

Carolyn L. Huntoon
Assistant Secretary for Environmental Management

William D. Magwood, IV
Director, Office of Nuclear Energy, Science and Technology

Ivan Itkin
Director, Office of Civilian Radioactive Waste Management

Laura S. H. Holgate
Director, Office of Fissile Materials Disposition

James F. Decker
Acting Director, Office of Science

Foreword

Environmental Quality is the Department of Energy's largest mission, accounting for over $7B of DOE's $19B budget in FY 2001. The Department is making significant progress in meeting its responsibilities for cleaning up the environmental legacy of the cold war nuclear weapons production program. In order to meet our cleanup goals while continuing to protect the environment, worker safety, and community health, the Environmental Quality program has an aggressive R&D component.

This Environmental Quality Research and Development Portfolio describes the Department of Energy investments in science and technology required to help clean-up the thousands of sites across the country that were contaminated as a consequence of building our nation's nuclear weapons. The Portfolio provides a look at the Department's investments from 1999 through the year 2001. It describes the major technical challenges in radioactive waste management, disposition and environmental restoration that our nation faces and the specific Department of Energy research and development activities being undertaken to address them.

The Portfolio correlates the R&D investments with the high-risk, high-cost, and long-term cleanup problems that are currently encountered in cleanup activities across the DOE complex. Chapter 2 provides an analysis of the Environmental Quality portfolio including discussions of the uncertainties and other factors affecting research and development, the distribution of investments by investment areas, the correlation of investments with life-cycle costs associated with the cleanup problems, and the trends in funding levels and distribution of investments from basic research through deployment of technologies. Chapters 3 through 10 (High-Level Waste through Basic Research) describe the background and specific details of each problem area and how specific R&D investments are being undertaken to meet the Department's environmental quality strategic goals and objectives. Each of these Portfolio chapters further defines the national context and drivers, strategic goals and objectives, uncertainties, investment trends and rationale, federal role and key accomplishments for each technical challenge.

Table of Contents

Executive Summary

Background and Purpose

The Department of Energy is one of the lead agencies with responsibility to help create and maintain the scientific and technological infrastructure that supports the nation's security and environmental integrity. Today it is one of the nation's largest sponsors of basic and applied research and development. In September 1997, the Department published the *U.S. Department of Energy Strategic Plan.* The plan was built on the four business lines—National Security, Energy Resources, Environmental Quality and Science. The Department has initiated a comprehensive effort to improve the planning and management of the large, complex research and development enterprise that supports the business line missions. This approach is based upon developing and managing business line research and development portfolios.

The Department's five volume R&D Portfolio provides, for the first time, a complete and comprehensive picture of the Department's research and development investment. The relative size and relationship of the four portfolios is illustrated in Figure ES-1. Historically research and development planning and management were conducted at the program or lower level. This approach resulted in overlaps, missed opportunities for collaboration and integration, and difficulty in identifying research gaps. The portfolio approach provides a comprehensive look at the entire research and development investment, in the context of the Department's missions and strategic objectives. This comprehensive picture provides the basis for analyzing, planning, and budgeting the research that will be needed in the future.

This volume is the first step in Environmental Quality (EQ) portfolio planning and management. It provides a baseline description of Fiscal Year 1999-2001 investments and combines selected R&D activities from four separate programs into an integrated portfolio. The portfolio is not organized by program, nor is it a comprehensive accounting of every program's activities. The portfolio does provide an accurate picture of the Department's investment in Environmental Quality R&D and is consistent with the President's budget.

Though it will identify some of the major issues and challenges of the future, this portfolio is not intended to be a planning document; it provides only a limited discussion of future investment plans. The longer-term view of the portfolio will be developed in the next phase of the process. A more complete discussion of the portfolio approach and management process is described in Volume I.

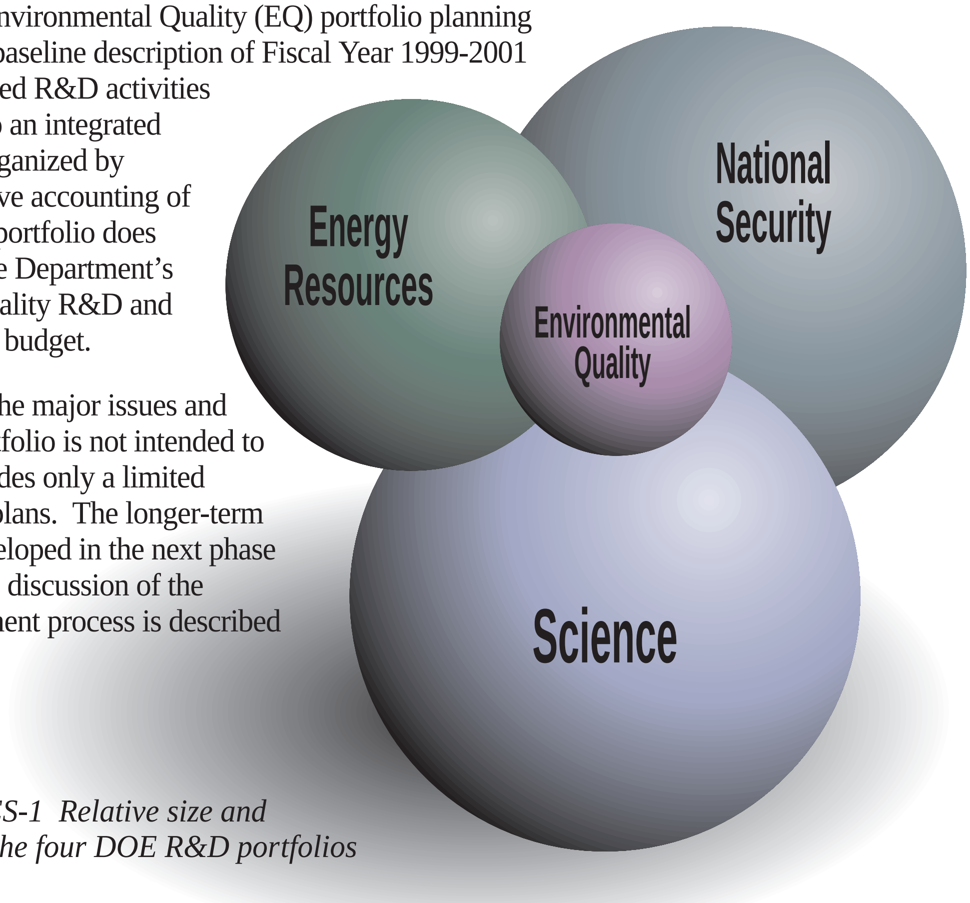
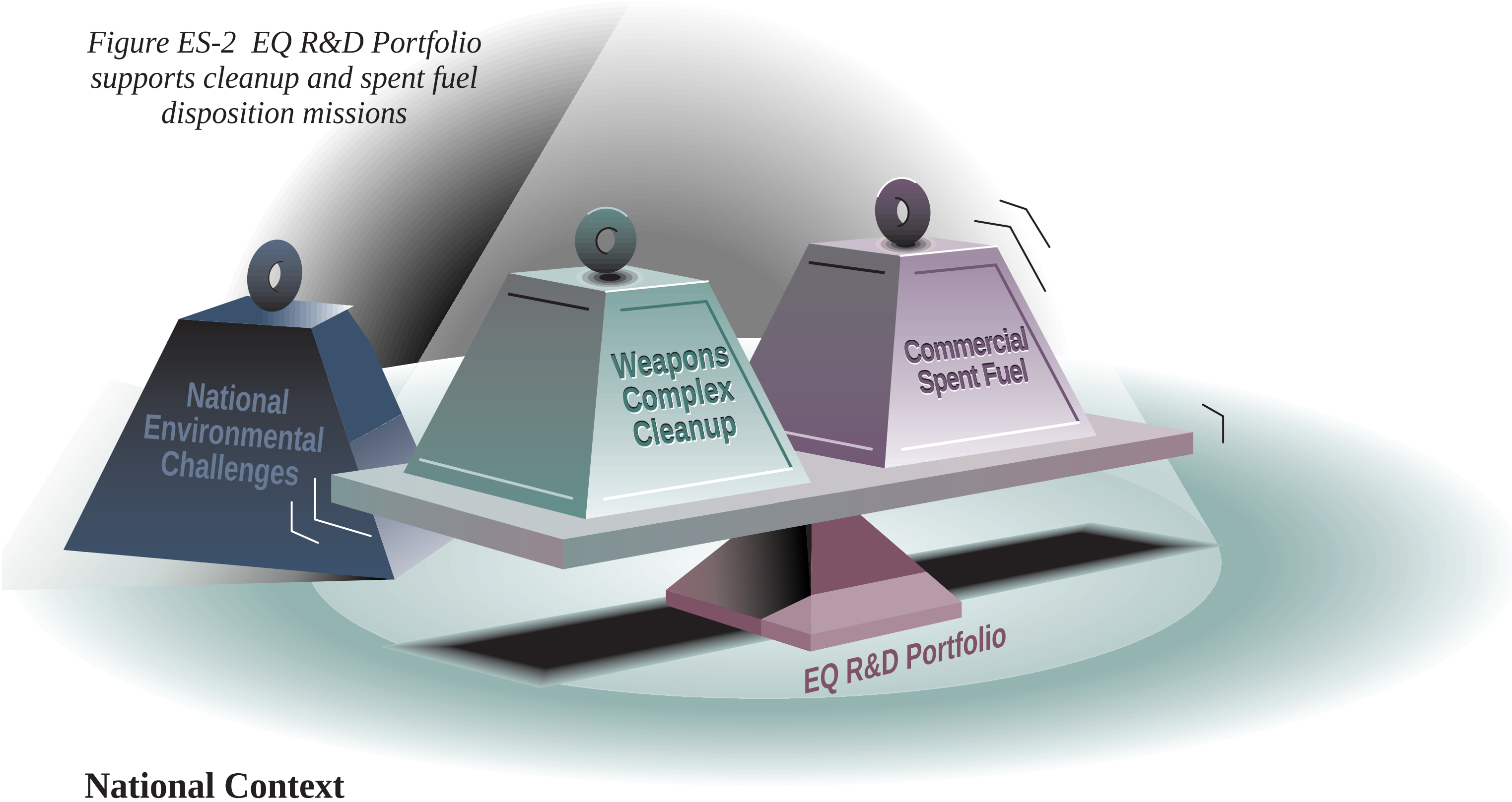


Figure ES-1 Relative size and relationship of the four DOE R&D portfolios

Figure ES-2 EQ R&D Portfolio supports cleanup and spent fuel disposition missions



National Context

The Environmental Quality business line encompasses three primary areas of responsibility:

- Reduce the environmental, safety and health risks and threats from the Department's facilities and materials.
- Safely and permanently dispose of civilian spent nuclear fuel and defense related radioactive waste.
- Provide the technologies and institutions to solve domestic and international environmental problems.

The current Environmental Quality portfolio is focused on supporting the first two areas, as depicted in Figure ES-2. The Science and Energy Resources R&D Portfolios partially support the third.

The principal program offices that support the Environmental Quality business line are Environmental Management, the Office of Civilian Radioactive Waste Management, the Office of Nuclear Energy, and the Office of Fissile Materials Disposition. The business line is also supported by the Office of Science through investments in basic and applied research.

Drivers

Cost, Technical Complexity, and Regulatory

The cost, duration, scope and complexity of the Department's environmental cleanup task were documented in *Accelerating Cleanup: Paths to Closure.* The cleanup program baseline encompasses over 350 cleanup projects with a life-cycle cost estimated at $168 billion (constant FY 1999 dollars). The life-cycle cleanup cost is based on providing solutions to:

- Three million cubic meters of buried radioactive and hazardous waste, 75 million cubic meters of contaminated soil, and 475 billion gallons of contaminated groundwater.
- 20,000 nuclear weapons production facilities contaminated with radioactive materials, hazardous chemicals, asbestos, and lead.
- Millions of gallons of high activity radioactive waste stored in large underground tanks; many of which have exceeded their design life, including some which have deteriorated, and leaked.
- 165,000 cubic meters of mixed waste located at facilities across the country.
- 150,000 metric tons heavy metal of reprocessed spent nuclear fuel currently in interim storage awaiting final disposition.
- An additional 80,000 metric tons heavy metal spent nuclear fuel is projected by 2035, requiring processing and disposition.
- Large quantities of fissile material residues and other processing intermediates in production lines or stored in a condition unsuitable to ensure long-term safety.

Many sites have entered into agreements with state regulatory agencies and the Federal Environmental Protection Agency. These agreements establish enforceable cleanup schedules and milestones and thus drive decision-making. The agreements are based on the numerous regulations associated with hazardous materials, radioactive material disposition, environmental protection, and pollution prevention.

Strategic Goal and Objectives

The *U.S. Department of Energy Strategic Plan* (September 1997) states that the Environmental Quality strategic goal is to "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." The seven objectives shown in Table ES-1, were established in the Strategic Plan to support this goal. These objectives describe *what* must be accomplished to achieve the Environmental Quality strategic goal, but do not prescribe *how* to perform the tasks. The functions necessary to fulfill the objectives have been identified and organized by waste type and activity to define the structure of the Environmental Quality R&D portfolio, depicted in Figure ES-3.

Table ES-1 Environmental Quality Strategic Objectives

1. Reduce the most serious risks
2. Cleanup as many sites as possible by 2006
3. Dispose of waste generated and make high-level wastes disposal ready
4. Prevent future pollution
5. Dispose of high-level radioactive waste and spent nuclear fuel
6. Reduce life-cycle costs of cleanup
7. Maximize the reuse of land and control risks

Portfolio Framework

The Environmental Quality R&D portfolio is best described by the functional relationship depicted in Figure ES-3. The portfolio is organized under three major portfolio elements: management of waste and materials; disposition of waste and materials; and, enhance future land use. Beneath the major portfolio elements are the seven major investment or problem areas. The bottom tier represents thirty six individual investments. These investments are discussed in detail in Chapters 3 through 9.

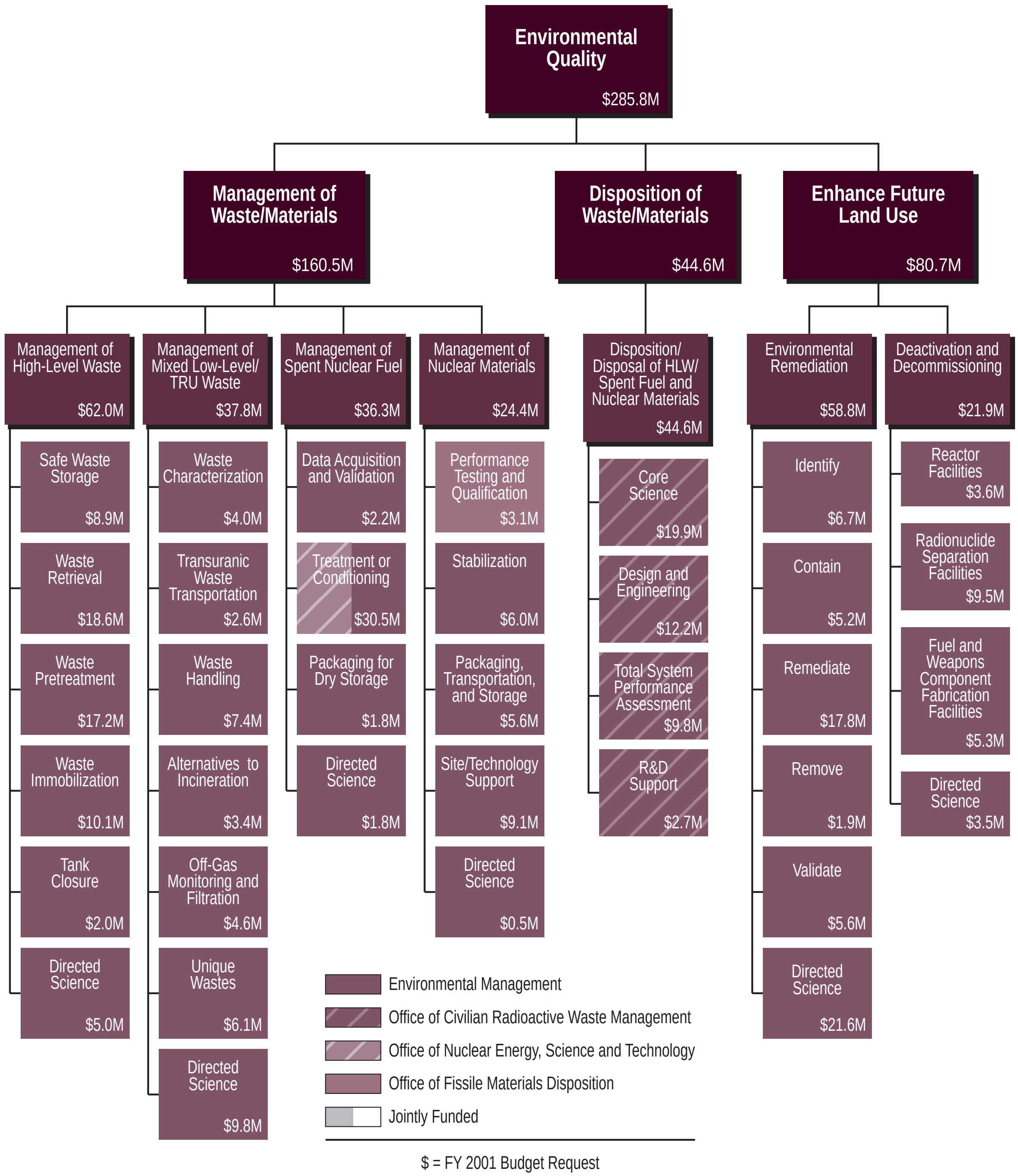


Figure ES-3 Environmental Quality R&D Portfolio

Portfolio Summary Trends

The overall Environmental Quality research and development funding decreased slightly in the FY 2001 request, and represents approximately four percent of the total business line. The major thrust remains investments in the high-risk, high-cost, and long-term problems associated with cleanup of the DOE complex and safe and permanent disposal of civilian spent nuclear fuel.

During FY 2001, efforts will focus on improving the balance of investments in the portfolio by transitioning basic research results into the applied research and development phase to address the Department's mid- and long-term cleanup needs.

Also, added emphasis will be placed in FY 2001 on developing long-term stewardship activities related to more reliable and cost-effective characterization and monitoring technologies and approaches. Long-term stewardship will ensure human health and the environment are protected after cleanup is completed, sites are closed, waste is emplaced for disposal, and/or facilities are stabilized for long periods awaiting possible further remediation.

The Environmental Systems Research and Analysis activities, conducted by the Idaho National Engineering and Environmental Laboratory, will continue focusing on research initiatives supporting subsurface science and long-term stewardship activities. Research activities will focus on better understanding of transport aspects of selective mass transport agents; chemistry of environmental surfaces; materials dynamics; characterization science; and computational simulation of chemical and mechanical systems. Emphasis will also continue on identifying opportunities for multi-site environmental management integration.

Regarding disposal, the Yucca Mountain Site Characterization Project is focused in FY 2001 on completing major R&D efforts to support a decision on whether to recommend the site to the President as the Nation's first repository for spent nuclear fuel and high-level radioactive waste in FY 2001.

DOE faces a number of overarching, multiple mission challenges for which the use of robotics and intelligent machines (RIM) can play a critical role. A roadmap that defines a path for RIM was developed in fiscal year 1999, and robotics activities are discussed throughout this portfolio as they apply to specific problem areas.

Portfolio Analysis

This portfolio provides the first opportunity to analyze the complete set of R&D investments supporting Environmental Quality activities. This analysis has identified five major findings, which are highlighted in the following overview of the analysis. The portfolio framework shown in Figure ES-3 correlates directly with the major problems facing the business line. **1.)** ***The portfolio is aligned with, and focused on, supporting complex-wide cleanup efforts and achieving the safe disposition of commercial spent nuclear fuel.*** This close-coupled relationship can be further illustrated by comparing R&D investments and projected life-cycle costs by problem area as shown in Figure ES-4.

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[1]c. Report of the Task Force on Alternative Futures for the DOE National Laboratories; Robert Galvin, Chairman, 1995.

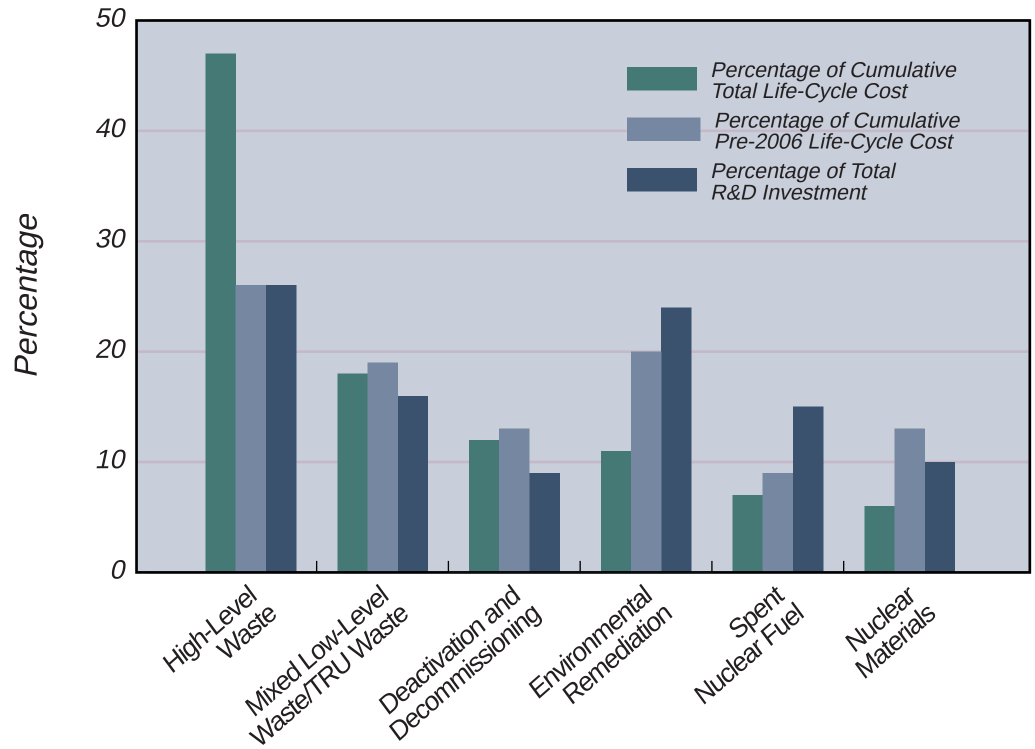


Figure ES-4 Life-cycle cost and annual R&D investment for weapons complex cleanup problem areas

2.) *The portfolio recognizes the need for, and attempts to invest across, a full spectrum of activities ranging from basic research through technology deployment.* The relative investment distribution across this spectrum is indicated by the blocks in each maturity stage in figure ES-5. High costs, the long-term nature of the cleanup, and the technical complexity require efforts to both reduce cost in the short term and invest for the future. Past Environmental Quality investments were focused on technology development and demonstration. The need for greater emphasis on basic science to help resolve long-term environmental issues was identified in the 1995 Galvin Report,[1] resulting in the appropriation of additional funds for this purpose by Congress in FY 1996. The Department also identified the need for increased technology deployment efforts to make sure developed technologies were more rapidly used. The current portfolio balance thus reflects the Department's renewed commitment to gain improved scientific understanding of its most difficult or intractable environmental problems, as well as to increase the deployment of new technologies needed to meet or accelerate schedules.

To invest across this spectrum requires a portfolio with participants that are diverse and distributed. The investment strategy also requires a portfolio that is leveraged. **3.) *The portfolio has been strengthened through the diversity of participants (universities, laboratories, site contractors, and industry), as illustrated in Figure ES-5, and the leveraging of activities with both internal and external participants.***

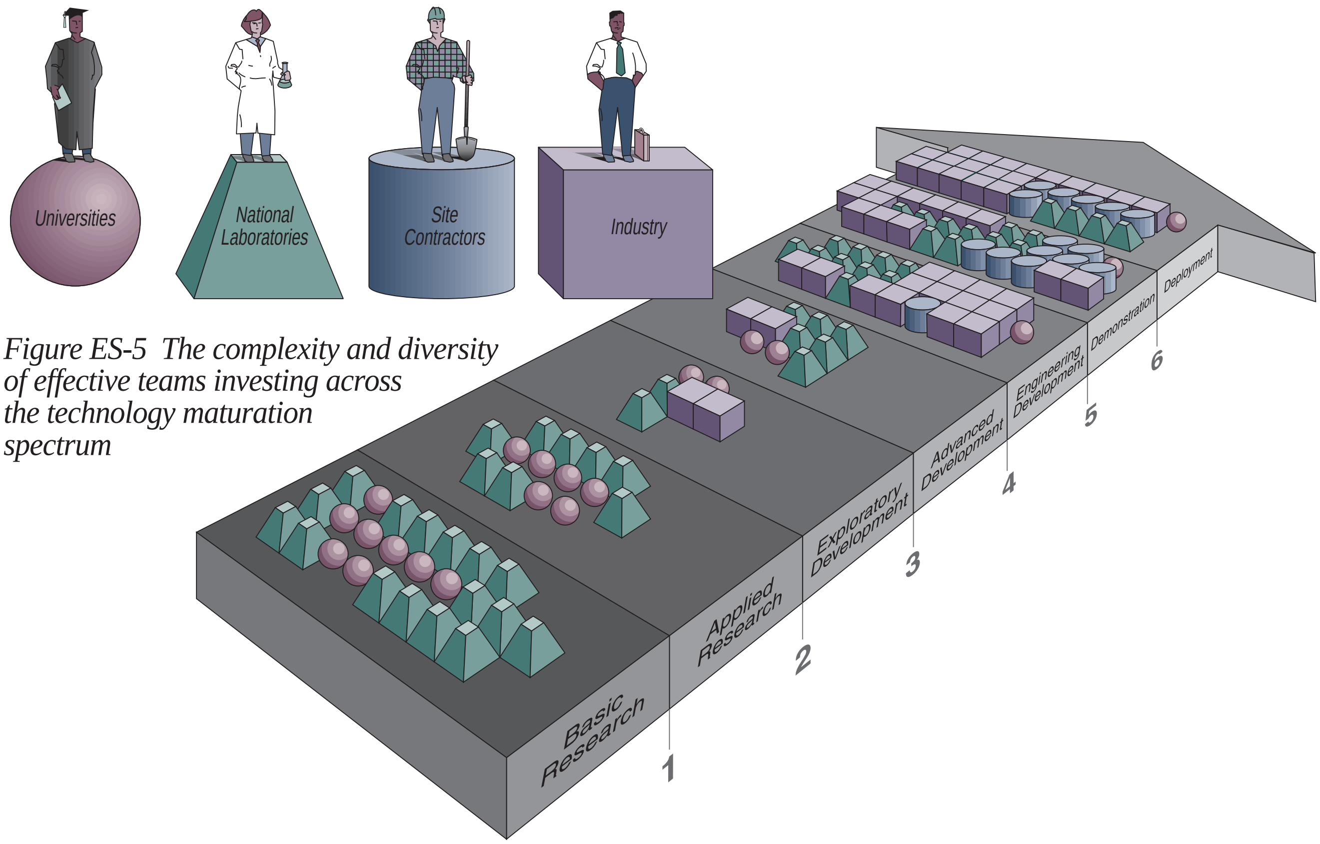


Figure ES-5 The complexity and diversity of effective teams investing across the technology maturation spectrum

The close coupled relationship, the broad spectrum of investments, and diverse participants are needed to meet the Department's environmental quality goal and objectives. **4.)** ***However, the overall Environmental Quality portfolio may be under invested to sustain achievement of existing mission objectives beyond the near term, i.e. beyond 2006***. The impacts of the under investment are currently being offset by directing funding toward basic research (relative to ongoing remediation) and the deployment of new technologies to support pre-2006 cleanup goals and commitments. Although this investment strategy should be successful in the near term, it is unlikely that this investment strategy can successfully support projected post-2006 cleanup costs and schedules.

5.) The Department should continue the portfolio planning process in order to improve the alignment of the four portfolios and make investment decisions that ensure the Department can help meet the nation's greatest challenges. The portfolio planning process has already enabled better integration within the individual portfolios. However, because there are significant interfaces and crosscutting elements, each of the business lines will contain some research activities that are relevant to other portfolios. The portfolio management process would benefit from improved coordination and a more integrated approach to these inter-portfolio activities.

● Strongly Support
◒ Moderately Support
○ Weakly Support
(1) Support as core value and operating principle

		Environmental Quality Objectives						
		Reduce the most serious risks EQ 1	Cleanup as many sites as possible by 2006 EQ2	Disposal of waste generated and make disposal ready EQ 3	Prevent future pollution EQ 4	Dispose of high-level radioactive waste and SNF EQ 5	Reduce life-cycle costs of cleanup EQ6	Maximize the reuse of land and control risks EQ7
Management of Waste/Materials	Management of High-Level Waste	◒	◒	●	(1)	●	●	○
	Management of Mixed Low-Level/ TRU Waste	◒	◒	●	(1)	N/A	◒	◒
	Management of Spent Nuclear Fuel	◒	◒	○	(1)	●	◒	○
	Management of Nuclear Materials	●	○	●	(1)	N/A	◒	○
Disposition of Waste/ Materials	Disposition of Waste/Materials	◒	○	◒	(1)	●	◒	○
Enhance Future Land Use	Environmental Remediation	◒	●	○	(1)	N/A	●	●
	Deactivation and Decommissioning	○	◒	○	◒	N/A	◒	●

Figure ES-6 Relationship of and support by portfolio elements to strategic objectives

In addition to the major findings, the analysis also identified the relationship and level of support that each investment area of the portfolio framework provides relative to the current Environmental Quality business line strategic objectives, illustrated in Figure ES-6.

External Factors and Uncertainties

There are a number of external factors and uncertainties that impact the Environmental Quality R&D portfolio:

- The final end-states for the cleanup effort are not fully defined. Decisions regarding the disposal or disposition of some waste types and materials have not been made.
- Federal Facility Compliance Agreements drive cleanup decisions and can inhibit or even prevent the development and maturation of better or improved alternative technologies.
- The inherent nature of the cleanup effort and the proximity of some sites to the general population necessitate stakeholder participation in cleanup decisions and technology use.
- Contract reform efforts, such as shifting to management and integration contractors and privatization, impact the portfolio's investment strategy and tactics.

Federal Role

To succeed, the Department must invest in those areas of high technical risk or limited potential for private investment. While the portfolio is leveraged with private sector investment, in the long run federal funds are needed to improve problem definition, provide a core investment base, and demonstrate the technical feasibility of innovative solutions. These investments ultimately reduce financial risk and attract greater private sector participation in cleanup activities. In addition to funding the portfolio, there are a number of aspects, some unique to the Department's role in Environmental Quality, that are worth discussion. These roles are identified in Table ES-2.

Table ES-2 Federal Role in the Environmental Quality Business Line and R&D Portfolio

The Department of Energy:

- Owns the problem
- Is a Major source for R&D funding
- Is a Primary participant in the R&D portfolio (through national laboratories and site contractors)
- Owns unique facilities for conducting R&D (e.g., hot cells and canyons)
- Coordinates federal investments in Environmental Quality R&D
- Provides global leadership to environmental quality efforts
- Is a Signatory of compliance regulations and agreements
- Is a market driver due to large percentage of the total environmental cleanup market

Key Accomplishments

A number of technologies from the Environmental Quality R&D portfolio have been developed and applied to solve environmental problems and to prepare for disposition of waste and materials in a geological repository. In many cases, ongoing research and development efforts continue to enhance the effectiveness or the scope of application of these technologies. Highlights of some of these technologies are provided below.

- Instrument improvements—portable detectors and nondestructive and nonintrusive examination techniques for stored waste and materials, contaminated surfaces, and soils; chemical sniffers and non-intrusive spatial metal detector arrays.

- New robots and tele-operated vehicles to characterize and retrieve waste in high radiation, chemically hazardous, and potentially explosive environments.

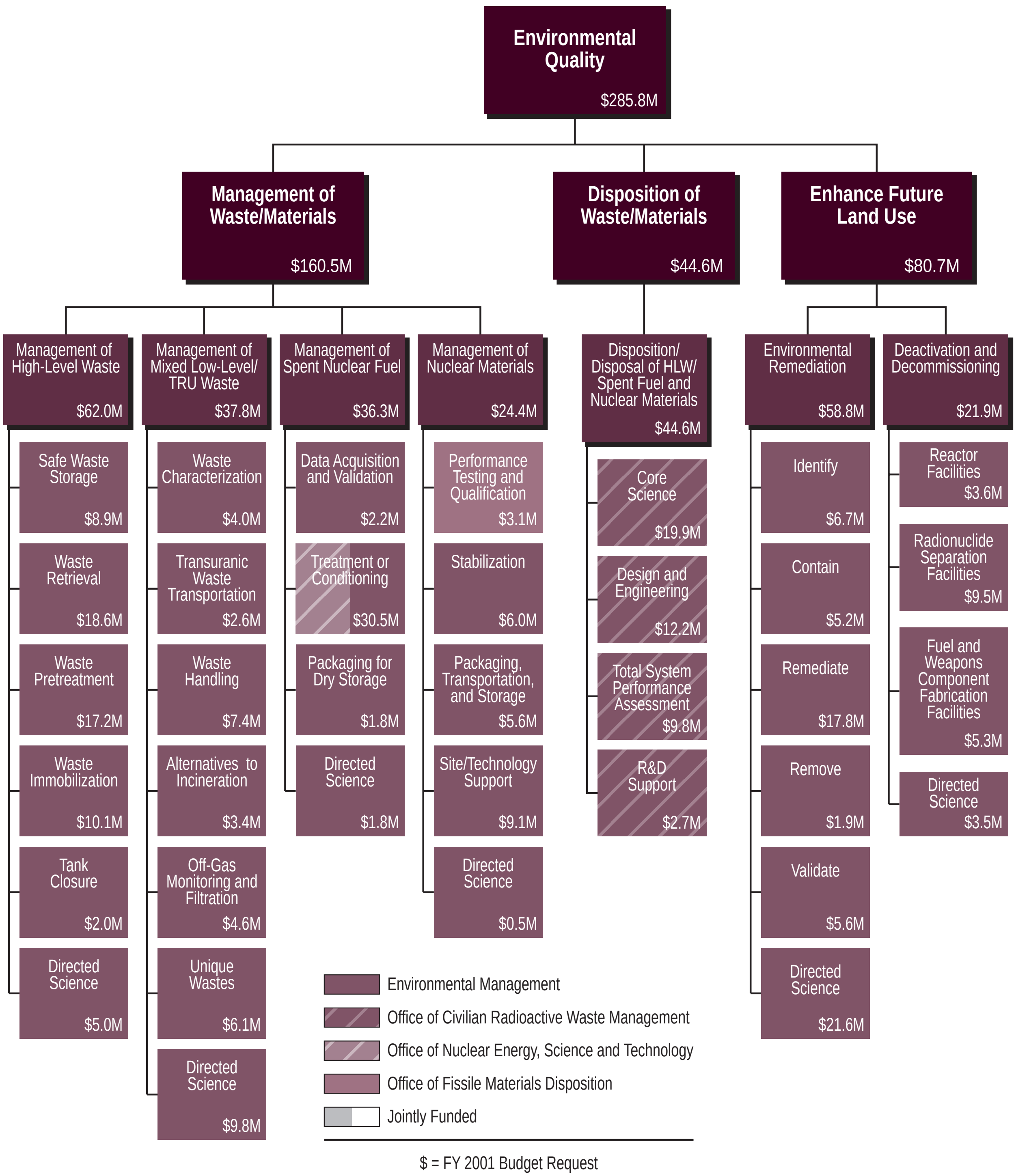
- Advanced chemical separations technologies for the removal of selected metals and radionuclides have already reduced life-cycle cleanup costs by over $6 billion.

- Improved technologies for stabilization of waste and materials: macroencapsulation, microencapsulation, calcination, and ceramification. Two vitrification facilities are safely operating.

- A geologic repository for the disposal of transuranic waste is in operation. A viability assessment for the disposal of spent fuel and high-level waste has been completed.

- R&D achievements also supported the successful remediation of over 50 contaminated sites through use of innovative technologies such as chemical washing, in situ bioremediation, vapor extraction, and the treatment of nonaqueous phase liquids.

Chapter 1
Introduction



Chapter 1

Introduction

Table of Contents

Background and Purpose

The Department of Energy is one of the lead agencies with responsibility to help create and maintain the scientific and technological infrastructure that supports the nation's security and environmental integrity. Today it is one of the nation's largest sponsors of basic and applied research and development. In September 1997, the Department published the *U.S. Department of Energy Strategic Plan.* The plan was built on the four business lines—National Security, Energy Resources, Environmental Quality, and Science. The Department has initiated a comprehensive effort to improve the planning and management of the large, complex research and development enterprise that supports the business line missions. This approach is based upon developing and managing business line research and development portfolios.

The Department's five-volume R&D Portfolio provides, for the first time, a complete and comprehensive picture of the Department's research and development investment. The relative size and relationship of the four portfolios is illustrated in Figure 1-1. Historically the Department's research and development planning and management was conducted at the program or lower level. This approach resulted in overlaps, missed opportunities for collaboration and integration, and difficulty in identifying research gaps. The portfolio approach provides a comprehensive look at the entire research and development investment, in the context of the Department's missions and strategic objectives. This comprehensive picture provides the basis for analyzing, planning, and budgeting the research that will be needed in the future.

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Though it will help identify some of the major issues and challenges of the future, this portfolio is not intended to be a planning document; it provides only a limited discussion of future investment plans. The longer-term view of the EQ portfolio will be developed in the next phase of the process. A more complete discussion of the portfolio approach and management process is described in Volume I of this set of DOE Research and Development Portfolios.

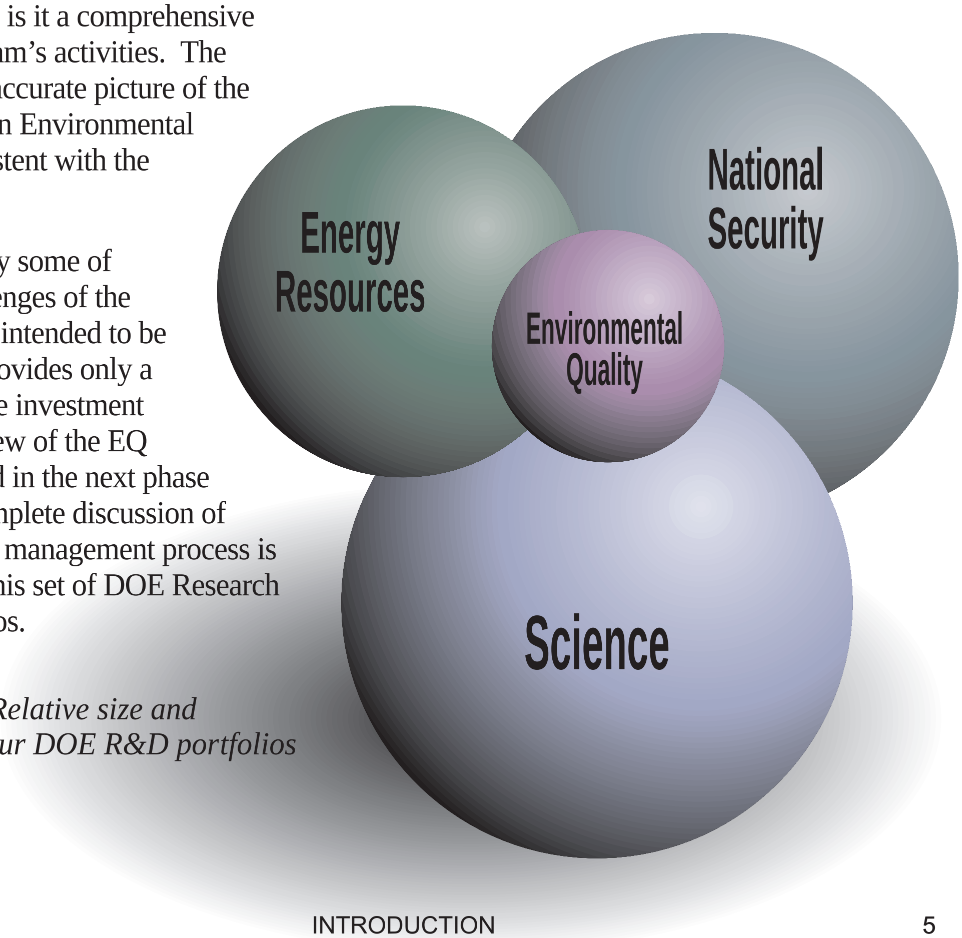


Figure 1-1 Relative size and relationship of the four DOE R&D portfolios

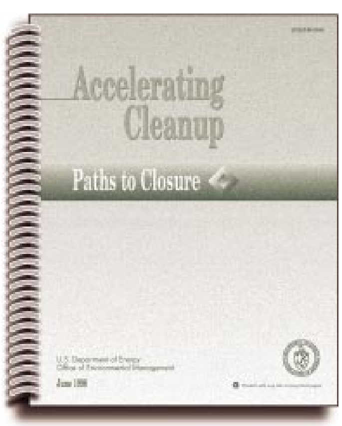
Figure 1-2 Environmental Quality primary areas of responsibility

Overview

The Environmental Quality business line encompasses the three primary areas of responsibility, illustrated in Figure 1-2.

- Reduce the environmental, safety and health risks and threats from the Department's facilities and materials.
- Safely and permanently dispose of civilian spent nuclear fuel and defense related radioactive waste.
- Provide the technologies and institutions to solve domestic and international environmental problems.

The Department of Energy has the responsibility to clean up the 50-year environmental legacy created by the nation's production of nuclear weapons and nuclear energy research and development. These activities generated large quantities of radioactive waste, contaminated large volumes of soil and water and many facilities, and created special nuclear materials that pose special health and safety hazards. The resulting environmental remediation and waste management program is the largest in the world. The magnitude of the cleanup task was defined in *Accelerating Cleanup: Paths to Closure*[1].



The Department's commitment to complete as much of the cleanup as possible by 2006 is based on very aggressive budget and planning scenarios, and in many instances assumes that scientific and technological advances will be made that provide significant cost savings and performance gains over current practices. In addition, cleanup activities must meet regulatory requirements and constraints associated with hazardous materials, radioactive material management and disposition, environmental protection (land, air and water), pollution prevention, resource recovery, and stewardship. In many instances these requirements and constraints are neither uniform nor consistent from one site to another.

[1] Accelerating Cleanup: Paths to Closure, DOE/EM-0362, June 1998.

In addition to its cleanup activities, DOE is also responsible for the safe disposal of commercial spent nuclear fuel, which is currently stored in facilities across the United States. The Nuclear Waste Policy Act (NWPA) describes the major regulations and policy relative to disposition of spent nuclear fuel. Long-term, deep geologic disposal has been determined to be the best method to provide long-term isolation of long-lived, hazardous radioactive materials. However, there is no precedent or experience in this area and much knowledge must be gained and technologies developed to ensure the successful performance of this repository.

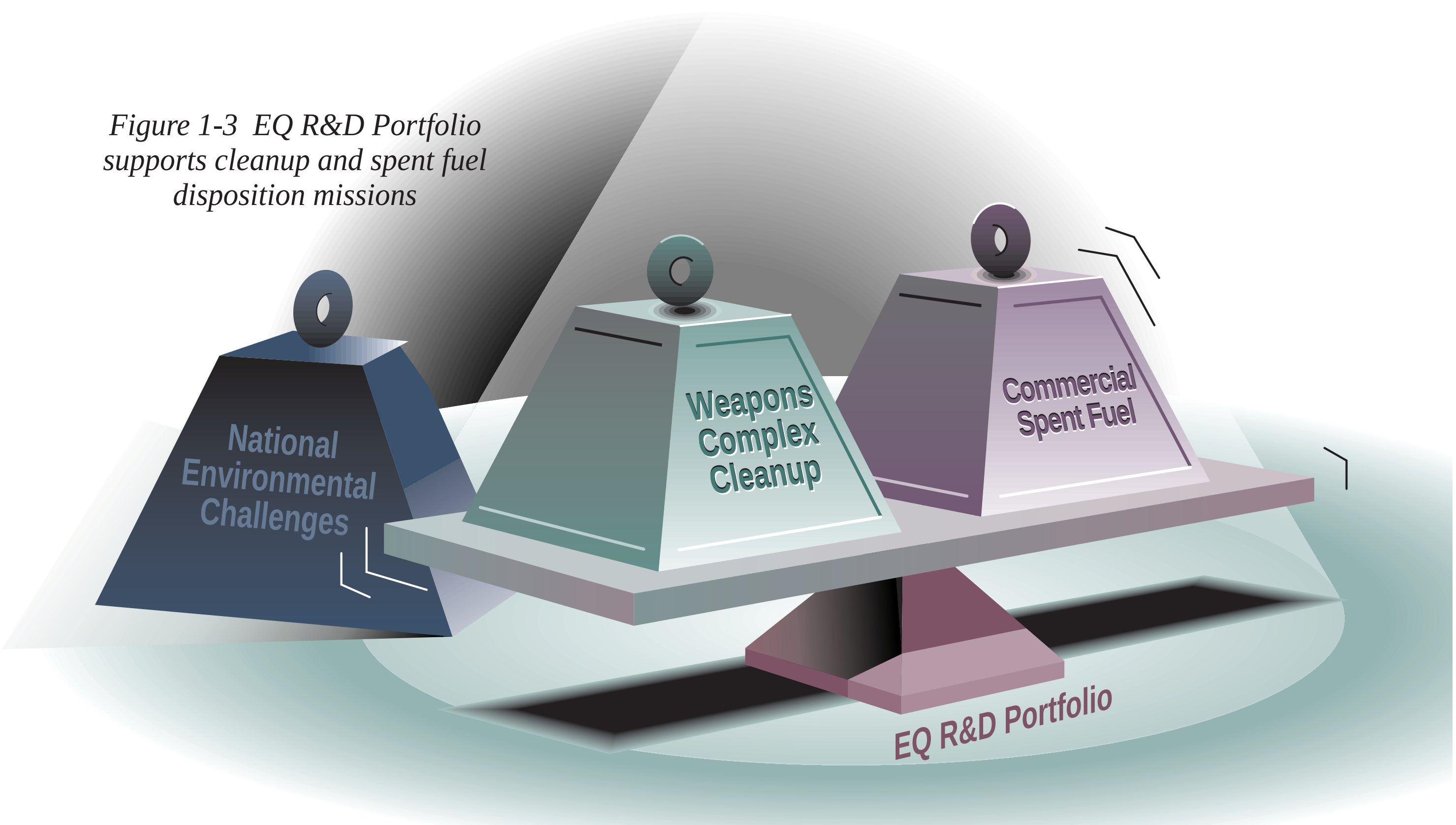
The *Nuclear Waste Policy Act* [Public Law 97-425, as amended by Public Law 100-203 and 102-486 (the Act)]:

- Established Department of Energy's responsibility to provide for the permanent disposal of the Nation's high-level radioactive waste (HLW) and spent nuclear fuel (SNF).

- Established the Office of Civilian Radioactive Waste Management (OCRWM) with the mission to provide for the disposal of SNF and HLW in a geologic repository.

The final area of responsibility is to provide both the technologies and institutions necessary to solve domestic and international environmental problems. Much of the scientific and technological infrastructure that has been developed and maintained to meet the first two responsibilities can be leveraged to support the third. However, the urgency of the Department's weapons legacy cleanup program and its commitment to meet aggressive cleanup goals has preempted direct support of this responsibility in the current portfolio, as illustrated in Figure 1-3. Partial support for meeting the nation's environmental challenges is also provided by the Science and Energy Resources R&D Portfolios.

Figure 1-3 EQ R&D Portfolio supports cleanup and spent fuel disposition missions



Environmental Quality Strategy

The Environmental Quality strategic goal and objectives are described in the DOE *Strategic Plan*[2], and are presented in Tables 1-1 and 1-2. This goal and set of objectives reflect the Department's commitment to respond to the challenges of the nation's environmental legacy.

The nation's nuclear environmental legacy presents several urgencies. The many real and perceived risks associated with radioactive contamination and nuclear materials must be addressed and satisfactorily resolved. Creating and maintaining safe conditions for these materials and contaminated sites is very expensive. Those costs continue until the radioactive materials, wastes and contaminated sites and facilities can be remediated or properly disposed. The current Environmental Quality strategy is narrowly defined and highly focused in response to the urgency of the cleanup program.

Table 1-1 Environmental Quality 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."

Table 1-2 Environmental Quality Strategic Objectives:

1. Reduce the most serious risks from the environmental legacy of the U.S. nuclear weapons complex first.
2. Clean up as many as possible of the Department's remaining 83 contaminated geographic sites by 2006.
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.
4. Prevent future pollution.
5. Dispose of high-level waste and spent nuclear fuel in accordance with the Nuclear Waste Policy Act as amended.
6. Reduce the life-cycle costs of environmental cleanup.
7. Maximize the beneficial reuse of land and effectively control risks from residual contamination.

[2] U.S. Department of Energy Strategic Plan, DOE/PO-0053, September 1997, pg. 25.

New and improved technologies and new knowledge are needed to meet the Department's cleanup commitments. The total estimated life-cycle cost of the environmental management program is $168B. Achieving this cost goal and associated program goals is based upon plans for site closures, many of which contain science and technology gaps. In many instances new or improved technologies are needed to meet projected cleanup costs. The portfolio employs the tactics presented in Table 1-3 to meet these needs.

Table 1-3 Portfolio Tactics for Weapons Complex Cleanup

- **Meet** the cleanup program's **highest priority needs**, including those on the critical path to closure and those that represent major technology gaps in project completion.
- **Reduce** the **cost** of the costliest cleanup projects:
- **Reduce technological risk** (where technology risk is defined as the programmatic risk that critical cleanup projects may not be completed on time and/or within budget due to a technology deficiency).
- **Accelerate and increase** the **deployment** of new and improved technologies into cleanup programs by bridging the gap between development and use.

Environmental Quality Portfolio Framework

The Department's cleanup effort is a unique, immensely complicated challenge of epic magnitude. The EQ strategic goal describes ***what*** the Department strives to achieve and the seven objectives describe the ***performance required*** to achieve the goal. Those objectives do not prescribe ***how*** to achieve the required performance. This epic cleanup challenge is most easily communicated through a set of "problem areas". The problem areas are carefully integrated sets of waste management, treatment, disposition and remediation activities that must be performed in a tightly orchestrated manner to complete the cleanup effort.

This problem area approach is also used to organize the R&D investments. The current R&D portfolio framework, like the EQ business line, is highly focused on specific issues. If the business line is broadened to more comprehensively address the nation's larger environmental needs, the portfolio must expand accordingly. The problem areas of the cleanup challenge are collected under three major portfolio elements:

- Management of Waste/Materials (High-Level Waste, Mixed Low-Level Waste/Transuranic Waste, Spent Nuclear Fuel, or Nuclear Materials);
- Disposition of Waste/Materials; or
- Enhance Future Land Use (Environmental Remediation and Deactivation and Decommissioning).

The major elements and problem areas are connected in the portfolio framework as illustrated in Figure 1-4.

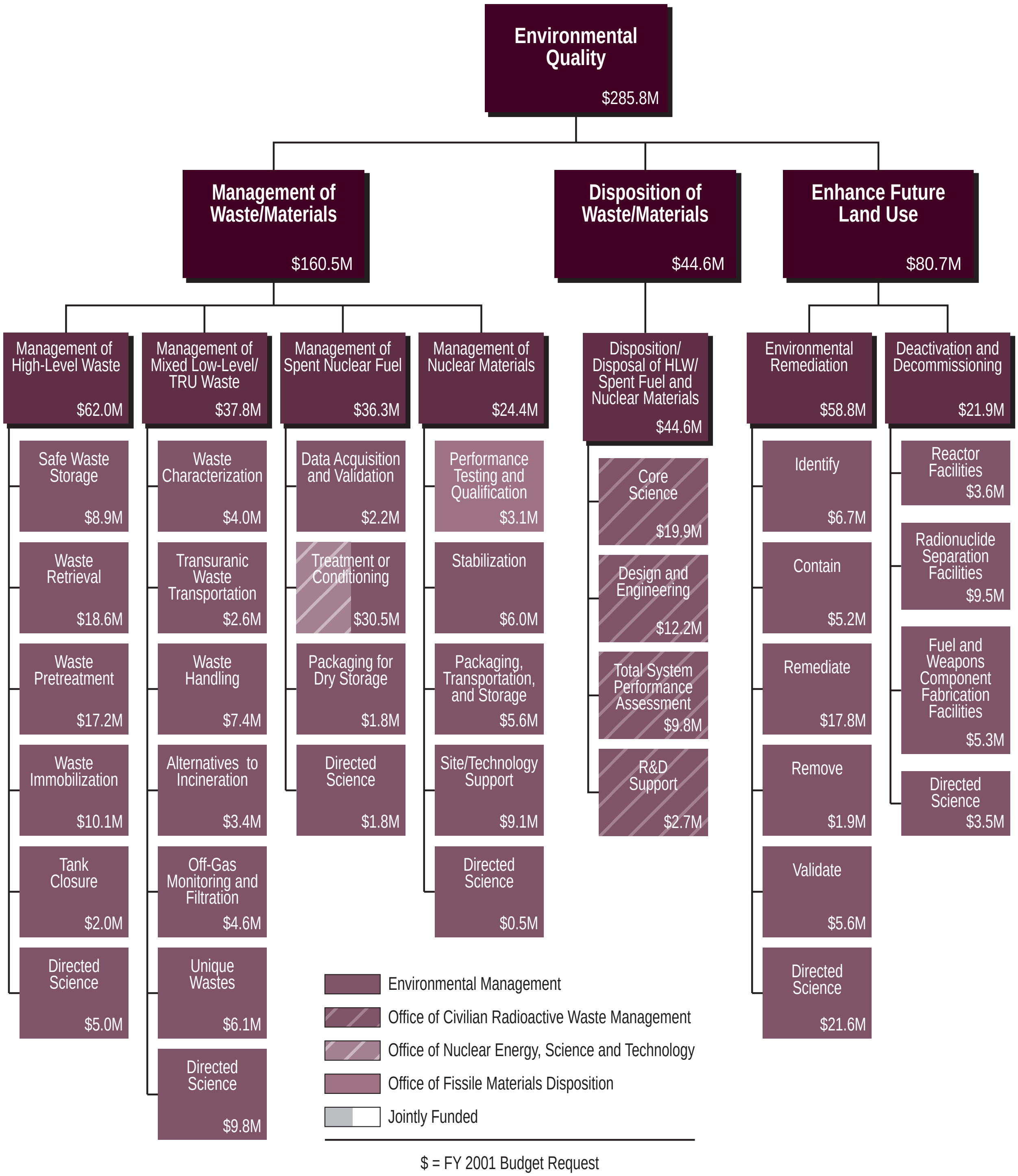


Figure 1-4 Environmental Quality R&D Portfolio Framework

The relationship of the elements of the portfolio to the seven Environmental Quality strategic objectives, and the level of support is illustrated in Figure 1-5 [3].

- ● Strongly Support
- ◒ Moderately Support
- ○ Weakly Support
- (1) Support as core value and operating principle

		Environmental Quality Objectives						
		Reduce the most serious risks EQ 1	Cleanup as many sites as possible by 2006 EQ2	Disposal of waste generated and make disposal ready EQ 3	Prevent future pollution EQ 4	Dispose of high-level radioactive waste and SNF EQ 5	Reduce life-cycle costs of cleanup EQ6	Maximize the reuse of land and control risks EQ7
Management of Waste/Materials	Management of High-Level Waste	◒	◒	●	(1)	●	●	○
	Management of Mixed Low-Level/ TRU Waste	◒	◒	●	(1)	N/A	◒	◒
	Management of Spent Nuclear Fuel	◒	◒	○	(1)	●	◒	○
	Management of Nuclear Materials	●	○	●	(1)	N/A	◒	○
Disposition of Waste/ Materials	Disposition of Waste/Materials	◒	○	◒	(1)	●	◒	○
Enhance Future Land Use	Environmental Remediation	◒	●	○	(1)	N/A	●	●
	Deactivation and Decommissioning	○	◒	○	◒	N/A	◒	●

Figure 1-5 Relationship of and support by portfolio elements to strategic objectives

Detailed discussions of science and technology investments and the resulting impacts and support of the Environmental Quality objectives are provided for each waste-type or activity group in Chapters 3 through 9. Each chapter describes a specific problem area. The description includes a discussion of drivers, federal responsibilities, an R&D overview, investment trends, accomplishments, and issues. Specific technology investments and supporting directed science investments for the specific problem area are also presented in each chapter. Chapter 10 describes the basic science investments (by the Science R&D Portfolio) that provide relevant support to and complement the directed science investments of the EQ R&D portfolio.

[3] The level of support indicated in Figure 1-5 was determined by the portfolio development team based upon input from each of the Programs or Offices in the Environmental Quality Business Line. This data has been reviewed by each Program or Office, the EMAB, the Strategic Laboratory Council and the Office of the Undersecretary.

Understanding the Portfolio Framework Elements

Understanding the problem areas and the magnitude and complexity of the challenges is critical to understanding the portfolio framework.

Management of Waste/Materials

Waste and materials come in many forms and types. The main waste categories or problem areas are listed and described in Table 1-4. The different types of wastes must be managed in accordance with different regulations, safety, health and environmental considerations. Management requires some or all of the following functions. Waste must be retrieved and characterized. Depending upon the type it must be treated, stabilized and then stored in an appropriate manner. Each of these functions may require special capabilities such as remote handling and special characterization techniques.

The significant technical challenges these wastes present, are further complicated by the sheer magnitude of the quantities that must be managed. For example, over 90 million gallons of high-level waste containing over 700 million curies of radioactivity are stored in large tanks at four major sites across the country. This volume is equivalent to over eight times the volume of oil spilled in the Exxon Valdez accident. Much of this liquid is highly corrosive, creating significant environmental and safety concerns about potential leaking by the storage tanks. In addition, there are many technical challenges in treating and preparing these wastes for disposal. The high level waste management investments are described in detail in Chapter 3.

The Department currently stores 165,000 cubic meters of mixed and transuranic (TRU) waste and 3,000,000 cubic meters of buried radioactive and hazardous waste. An additional 221,000 cubic meters of mixed and TRU waste is projected to be generated as a result of future remediation and deactivation and decommissioning activities. As illustrated in Figure 1-6, this covers a football field

Table 1-4 Description of Waste Types

High-level waste: the radioactive by-product generated from processing irradiated fuel to separate usable plutonium and other isotopes for weapons, research and new fuel.

Transuranic (TRU) waste: waste that contains alpha-emitting transuranic elements with half-lives greater than 20 years whose combined activity level is at least 100 nanocuries per gram of waste at the time of assay.

Low-level waste: composed of all radioactive waste not classified as high-level waste, TRU waste, spent nuclear fuel, or natural uranium or thorium by-product material.

Mixed waste: waste that contains both radioactivity and hazardous chemicals and materials such as mercury, PCBs, and organic solvents.

Spent nuclear fuel: nuclear fuel which has been irradiated, and which, through fission activation and decay, contains multiple radioactive elements with varying chemical and radiological properties.

Nuclear material: includes uranium, plutonium, and other fissile materials in the form of metals, oxides, residues, and processing intermediates left from nuclear weapons production, along with laboratory samples, radiation sources, and rare and man-made isotopes.

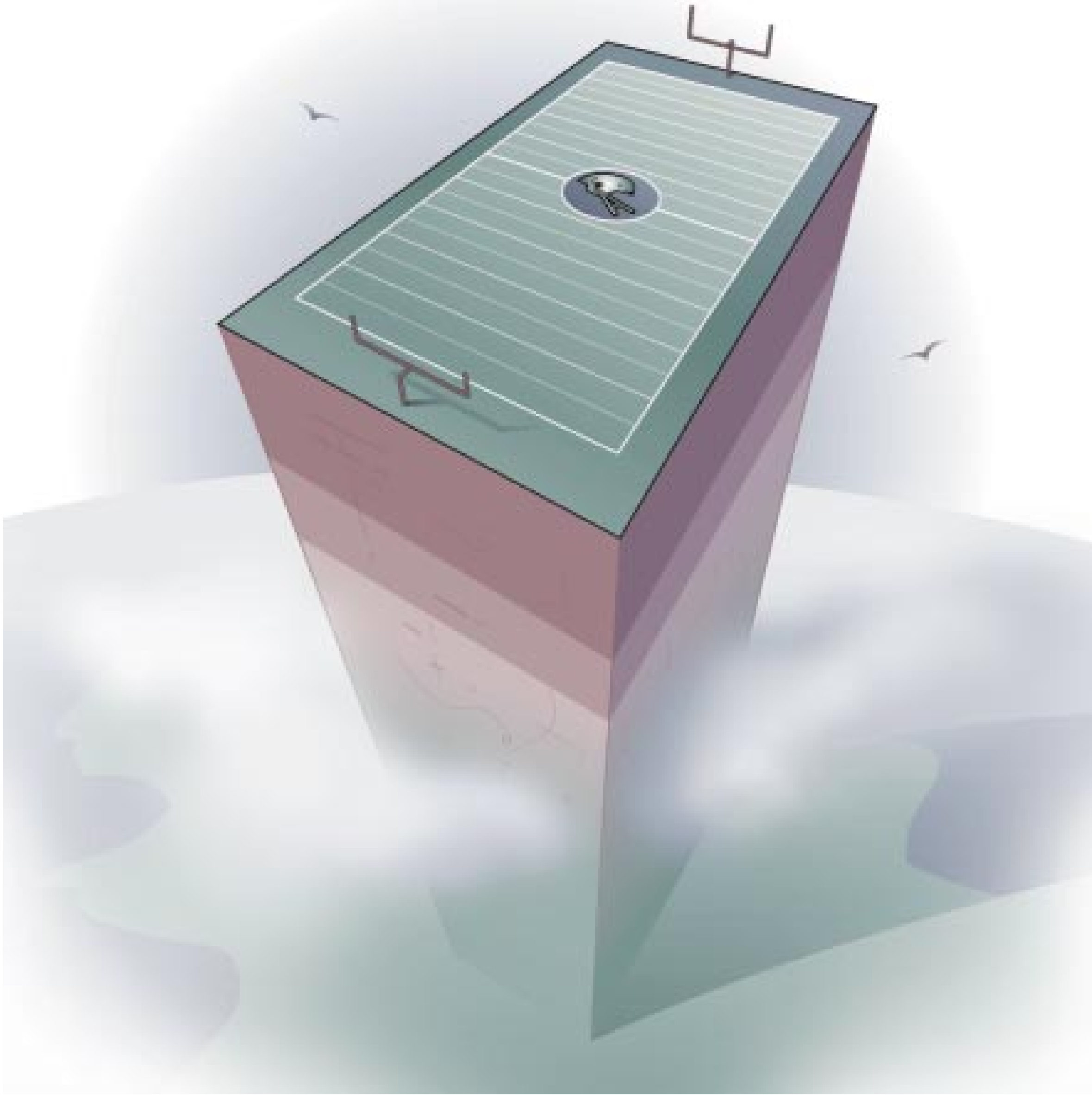


Figure 1-6 The volume of mixed, TRU and solid radioactive and hazardous waste covers a football field to a height of almost a half mile

almost a half mile high! The special challenges presented by these wastes are detailed in Chapters 3 and 8.

Approximately 2500 metric tons heavy metal of spent nuclear fuel have been, or are projected to be, generated from the Department's weapons production, naval, and research reactors. These materials are essentially nuclear reactor fuels that have been used, but still generate considerable heat and under certain conditions are capable of sustaining a chain reaction. Therefore special storage must be provided until the material can be safely dispositioned at an appropriate site, such as a geologic repository. Investments supporting spend nuclear fuel activities are described in Chapter 5.

In addition to the 2500 metric tons of spent nuclear fuel, DOE has responsibility for over 500,000 metric tons of nuclear materials, comprised of uranium and medical isotopes and industrial and laboratory radiation sources. This mass of materials is equivalent to the weight of twelve ships the size of the Titanic. Nuclear materials management is described in greater detail in Chapter 6.

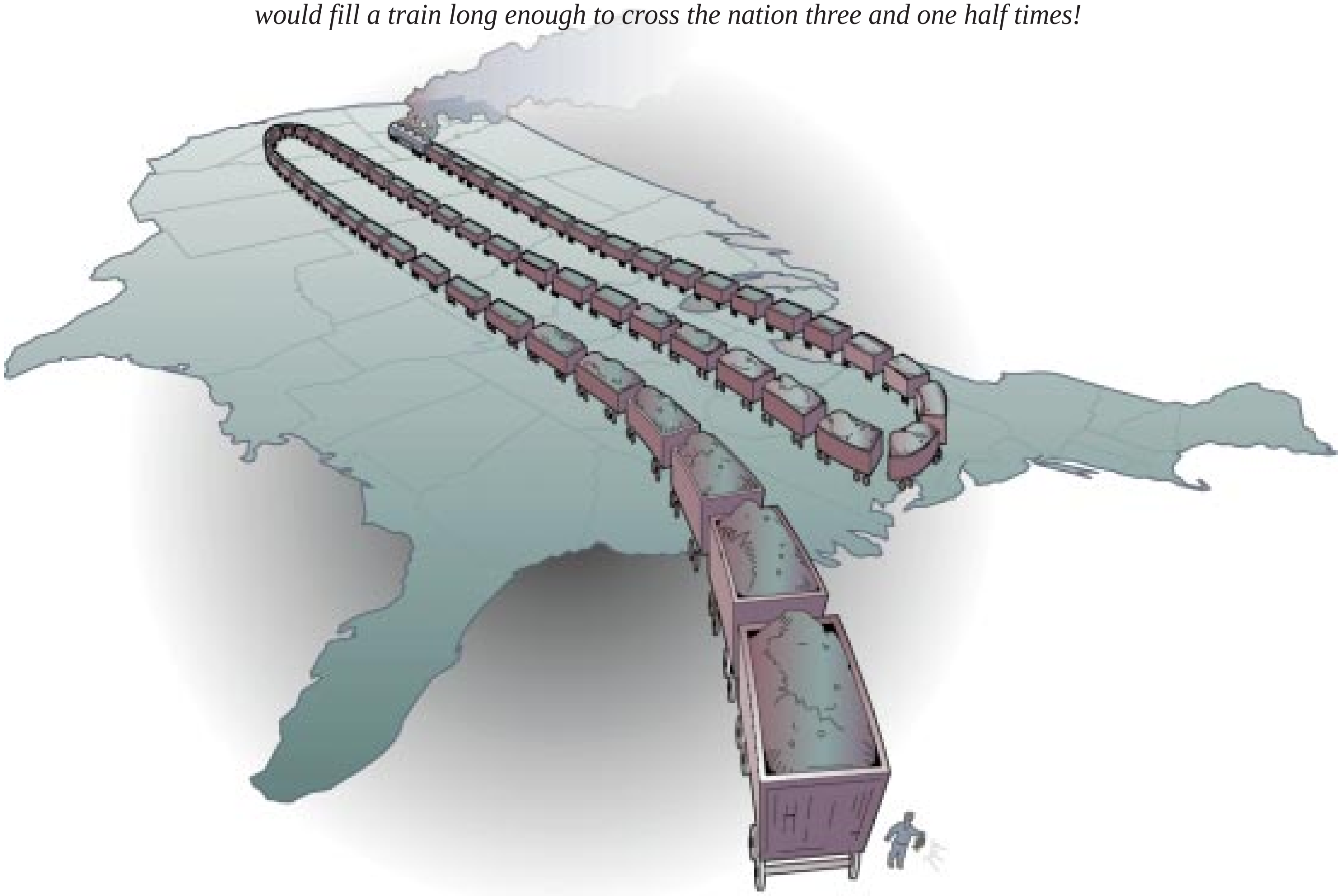
Disposition of Waste/Materials

Projections of spent nuclear fuel generated through 2035 indicate that as much as 86,700 metric tons heavy metal will be produced from electric power generation at commercial nuclear reactors and approximately 2500 metric tons heavy metal from Department research, test, weapons production, and naval propulsion reactors. That is equivalent to placing the tonnage of two Titanics in a geologic repository. In addition, immobilized high-level radioactive waste will require permanent isolation in a geologic repository. Estimates of the numbers of HLW canisters vary, but it is expected that over 20,000 canisters of HLW will be produced. Long-term geologic disposition has never been demonstrated and a large number of questions must be answered. Answers to these questions are difficult to obtain. This research is complicated by the fact that the repository's compliance period extends over many thousands of years, and no precedent exists to validate performance over this timeframe. The investments for materials and waste disposition are described in Chapter 7.

Enhance Future Land Use

The Department is also responsible for an estimated 3 million cubic meters of buried solid radioactive and hazardous wastes, 75 million cubic meters of contaminated soil, and 475 billion gallons of contaminated groundwater. The magnitude of the environmental remediation challenge presented by these quantities is shown in Figures 1-7 and 1-8, and is discussed in Chapter 8.

Figure 1-7 The volume of contaminated soil to be remediated would fill a train long enough to cross the nation three and one half times!



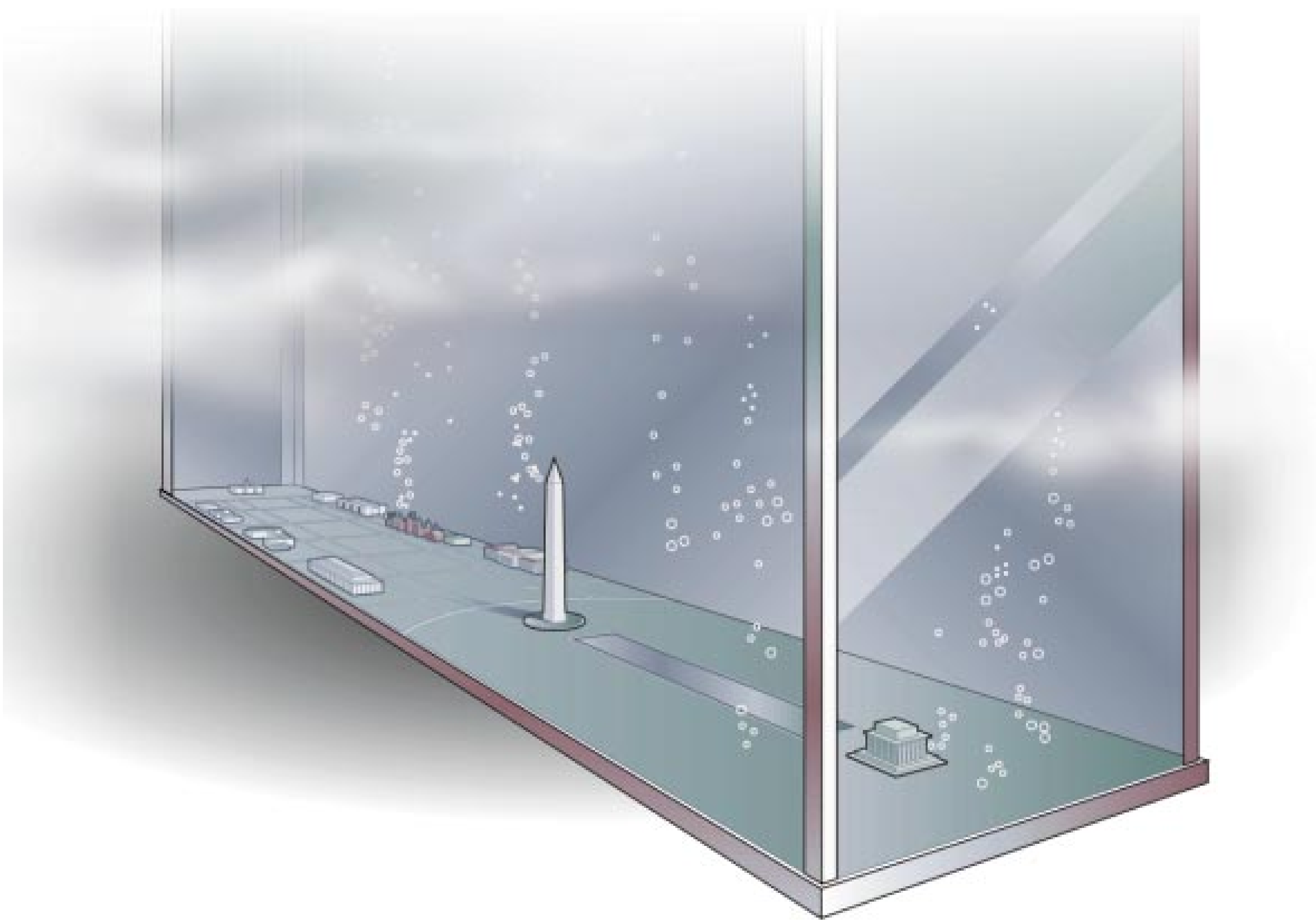


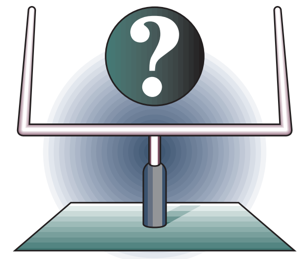
Figure 1-8 The volume of contaminated groundwater to be remediated would fill an aquarium with a base the size of the Washington Mall, seven miles high!

In addition to the environmental remediation activities, the cleanup program must also address over 20,000 facilities which require deactivation and decommissioning, as will hundreds of commercial nuclear power plants and university research reactors. Many of these facilities present very significant challenges due to the highly radioactive and hazardous environments encountered. The R&D investments supporting deactivation and decommissioning activities are described in Chapter 9.

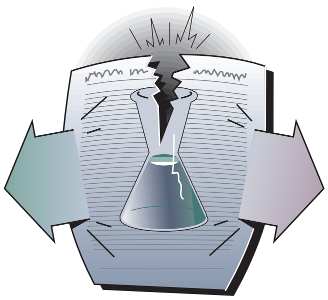
Factors Affecting EQ R&D Portfolio

The portfolio encounters the general uncertainties associated with research and development. However, there are additional factors and uncertainties that impact the EQ R&D portfolio.

Portfolio Planning with Moving Targets

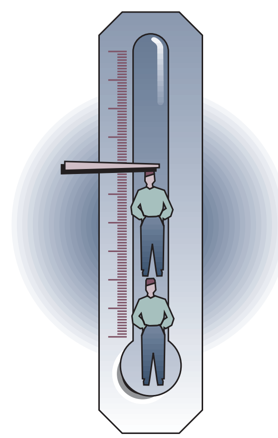


End states are not fully defined for many of the Department's larger sites and decisions regarding disposal or disposition of some waste types and materials have not been formalized. Achieving safe and affordable end states and final disposal or disposition will require a significant amount of effort and resources. The use of new science and technology is required to move closer to the end states and make further progress in the final disposal of our waste. This progress will allow the Department to better focus our R&D efforts on completion of the final cleanup and disposal missions.



Compliance-Driven Decision-Making

Federal Facility Compliance Agreements and environmental laws and regulations drive the Department's cleanup decisions. Unfortunately, some of these decisions have been made before all potential solutions are identified and/or developed. This may inhibit the development and maturation of potential alternative technologies. In some cases, existing scientific knowledge is simply insufficient to make fully informed decisions. In short, the technical complexity coupled with external regulatory uncertainty and variability can result in complex and sometimes conflicting regulatory requirements being imposed by state and federal regulatory agencies. This is not the best environment for the rapid introduction of new technology.

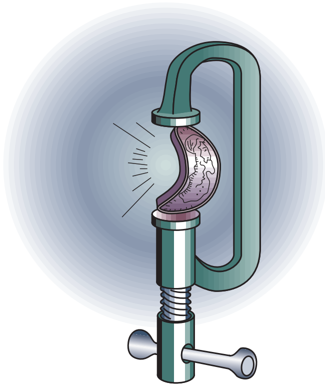


Technology Decisions and Stakeholder Values

Stakeholders are a major factor in developing cleanup options, in decision making, and in the use of new technology. Due to the inherent nature of the cleanup effort and the proximity of some sites to the general population, stakeholders have a high interest in cleanup activities. They play a key role in determining the levels of acceptable risk and can strongly affect the required level of cleanup and the ability or will of the government to fund these efforts. Seeking their participation throughout the process of solving cleanup problems and making investment decisions is critical.

Balancing Contract Reform, Privatization, and Investments

Contract reform efforts such as shifting to management and integration contracts and privatization of cleanup efforts are tactics to improve management and reduce costs. Contract reform efforts are relatively new and will need further development and improvement to ensure optimum performance. Coupling contract reform with R&D investments can help encourage industry investment in the development of new science and technology for waste management and environmental remediation.



However, this has not yet proved effective in areas that do not offer an attractive commercial market. Privatization is an alternative to traditional government-owned facilities and cost-reimbursement contracts. Under privatization, privately financed facilities are selected in competitive bids, usually operate on a fixed-price basis, and receive a fee once cleanup goals (as specified in contracts) are met. The potential for profit provides the incentive for the private sector to introduce innovative and cost effective technologies. The private sector will weigh the potential for increased profit resulting from more efficient technology against any increase in programmatic risk. As a result, lower total costs to the government are possible. Privatization of the Department's cleanup efforts has been difficult in areas where there is not potential commercial market, i.e., where the Department is the only potential customer.

Role of the Federal Government in Environmental Quality R&D

The federal government, as well as industry, must invest in basic and applied science to accomplish its mission and to maintain productivity and competitiveness in the global economy. The trend in the United States has become one in which industry is shifting investments to near-term R&D to improve short-term gains. Thus, developing and sustaining the long-term scientific and technological foundations for economic productivity is becoming the responsibility of publicly funded science. In addition to this universal federal role in R&D, there are a number of rather unique aspects of the federal role in the EQ business line, shown in Table 1-5.

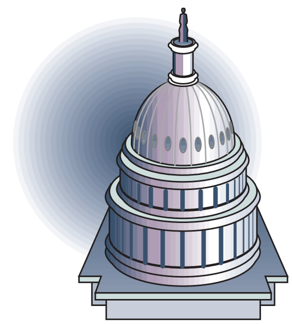


Table 1-5 Federal Role in the Environmental Quality Business Line and R&D Portfolio

The Department of Energy:

- Owns the problem
- Major source for R&D funding
- Primary participant in the R&D portfolio execution (through the national laboratories and site contractors)
- Owner of unique facilities for conducting R&D (e.g., hot cells and canyons)
- Coordinates federal investments in Environmental Quality R&D
- Provides global leadership to environmental quality efforts
- Signatory of compliance regulations and agreements
- Is a market driver due to large percentage of the total cleanup market

Managing the Investment Portfolio

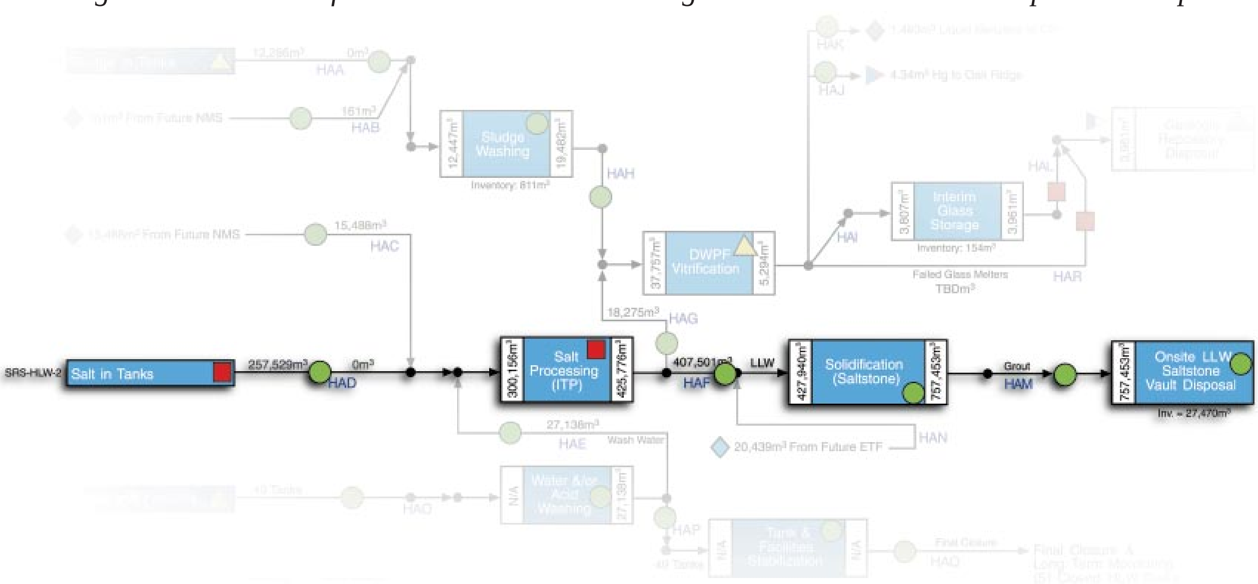
While the portfolio provides an integrated picture of EQ R&D investments, it is not yet managed as an integrated investment. The disposition element of the portfolio is managed by the Office of Civilian Radioactive Waste Management in accordance with the major founding and directive legislation[4]. The major responsibility for the environmental cleanup task resides with Environmental Management.

The approach to managing Environmental Management funded investments are in transition. The new management approach is described in recently published strategic and program plans[5], and is currently being implemented. Four essential elements of this new R&D management approach are briefly described below.

End State Development—A Systems Engineering Approach

Systems engineering principles and methodologies have been used to help define the end states that must be attained to achieve the cleanup goals. This type of approach has been confirmed by a recent study by the National Research Council[6]. The creation of complex-wide disposition maps for waste and materials has provided an opportunity to identify technology needs, alternative disposition scenarios, and the increased potential to leverage resources and facilities across the complex. Figure 1-9 provides an illustration of a disposition map. The map displays a "red light" for salt reprocessing, indicating a major technology need exists for this cleanup activity. The identification of technology needs and gaps and programmatic risk provide the basis for prioritization of Environmental Management R&D investments.

Figure 1-9 Portion of the Savannah River Site-High Level Waste Baseline Disposition Map



[4] The *Nuclear Waste Policy Act*, Public Law 97-425 as amended by Public Law 100-203 and 102-203.

[5] *Environment Management Strategic Plan for Science and Technology* (November 1998) and *Environmental Management Research and Development Program Plan* (November 1998)

[6] *An End State Methodology for Identifying Technology Needs for Environmental Management, with an Example from the Hanford Site Tanks*, Committee on Technologies for Cleanup of High-Level Waste in Tanks in the DOE Weapons Complex; Board on Radioactive Waste Management; Commission on Geosciences, Environment, and Resources; National Research Council, National Academy Press, Washington, D.C. 1999

Customer-Driven Research and Development

Activities necessary to achieve known end states are defined in the cleanup projects. Needs are identified in these projects by the cleanup project manager, that is, the R&D customer, and form the basis for developing the investment portfolio. The process of identifying needs, developing responsive research and development work packages, and incorporating them into planning, budget formulation and execution is illustrated in Figure 1-10 [7].

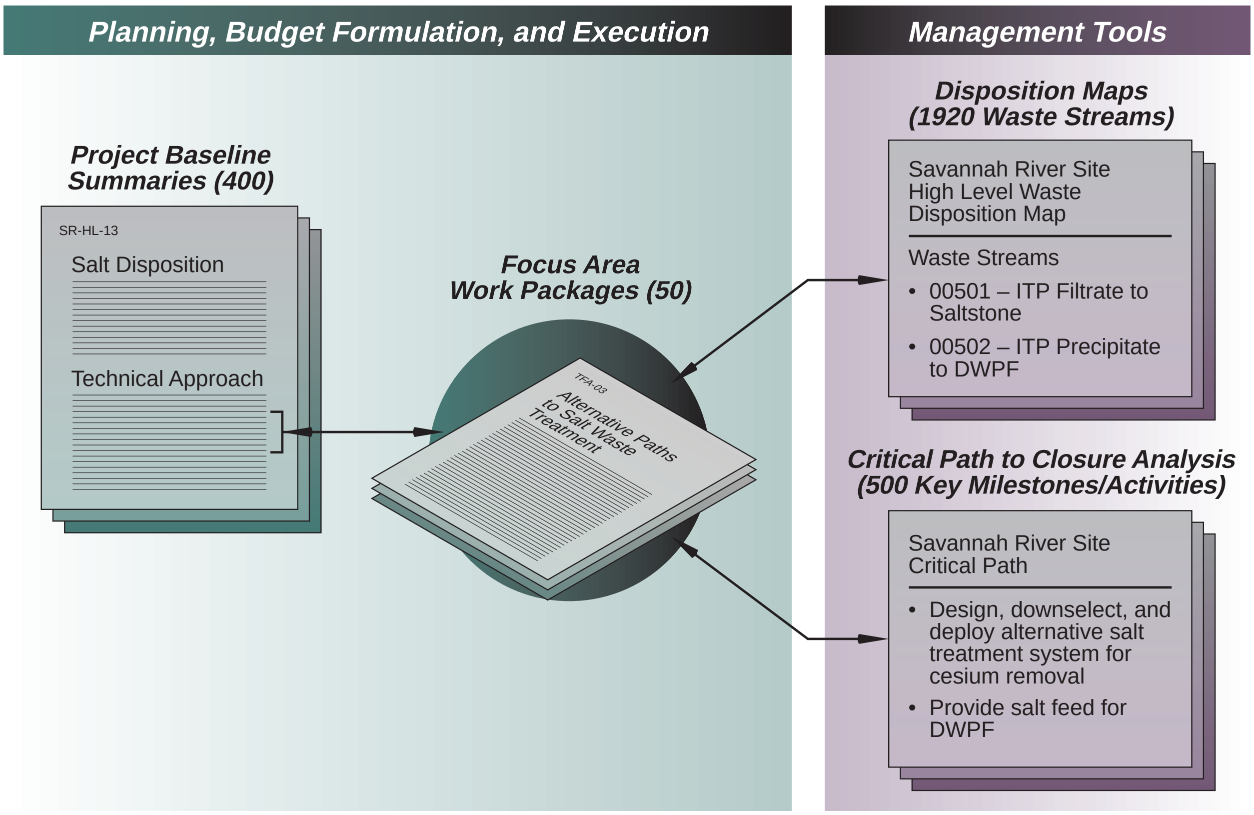


Figure 1-10 Integration of R&D Work Packages with Complex-wide budget analysis and management processes

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[7] All cleanup projects are described in documents called Project Baseline Summaries (PBSs). The PBSs are grouped into sets of like problem areas, and the science and technology needs for each problem area are described in Focus Area work packages. Technology needs are also developed from gaps identified in waste disposition maps and by analysis of critical path milestones.

Prioritizing Portfolio Investments

A set of quantitative parameters are used to evaluate and score each research and development work package. The portfolio can then be developed in response to the highest scoring proposals with confidence that, with the funding available, the portfolio will be the "right" portfolio; it will address the most important research and development needs and have the greatest potential impact. Figure 1-11 illustrates the elements of the quantitative analytical process.

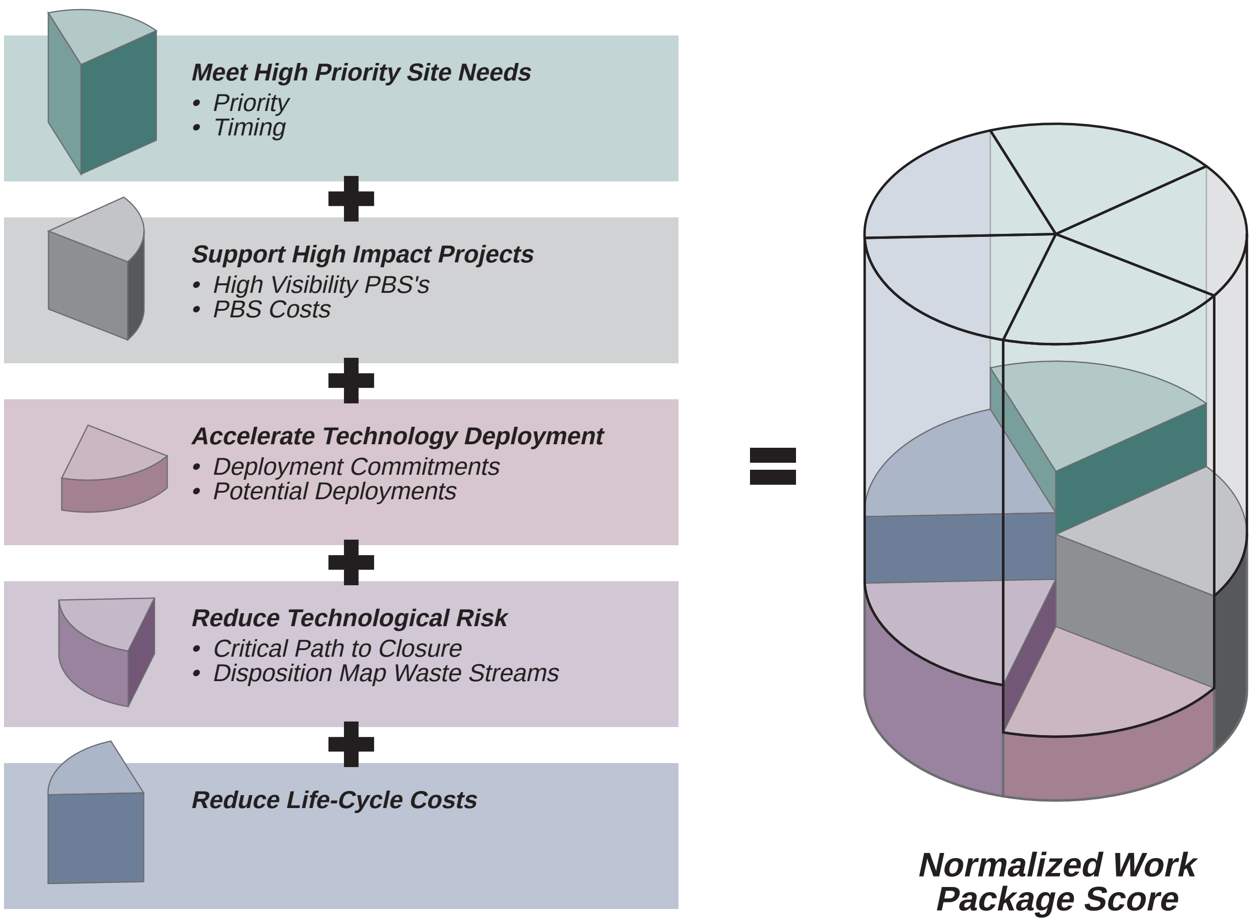


Figure 1-11 Process for quantitative determination of work package value score

Performance Measures—Managing and Evaluating the Portfolio

The Environmental Management science and technology strategic and program plans describe ***what*** and ***how*** the research and development activities are to support the cleanup enterprise. The management approach ties the investments directly to cleanup projects. The corporate research and development performance measures are used to measure ***how well*** the Environmental Management research and development investments have met cleanup project needs. The cleanup program manager defines the R&D needs, the level of performance necessary to meet those needs, and reports the actual level of performance. These performance measures, defined and reported by the customer, provide the basis to assess the performance of the portfolio and serve as a basis for modification and improvement. The four performance measures are illustrated in Figure 1-12.

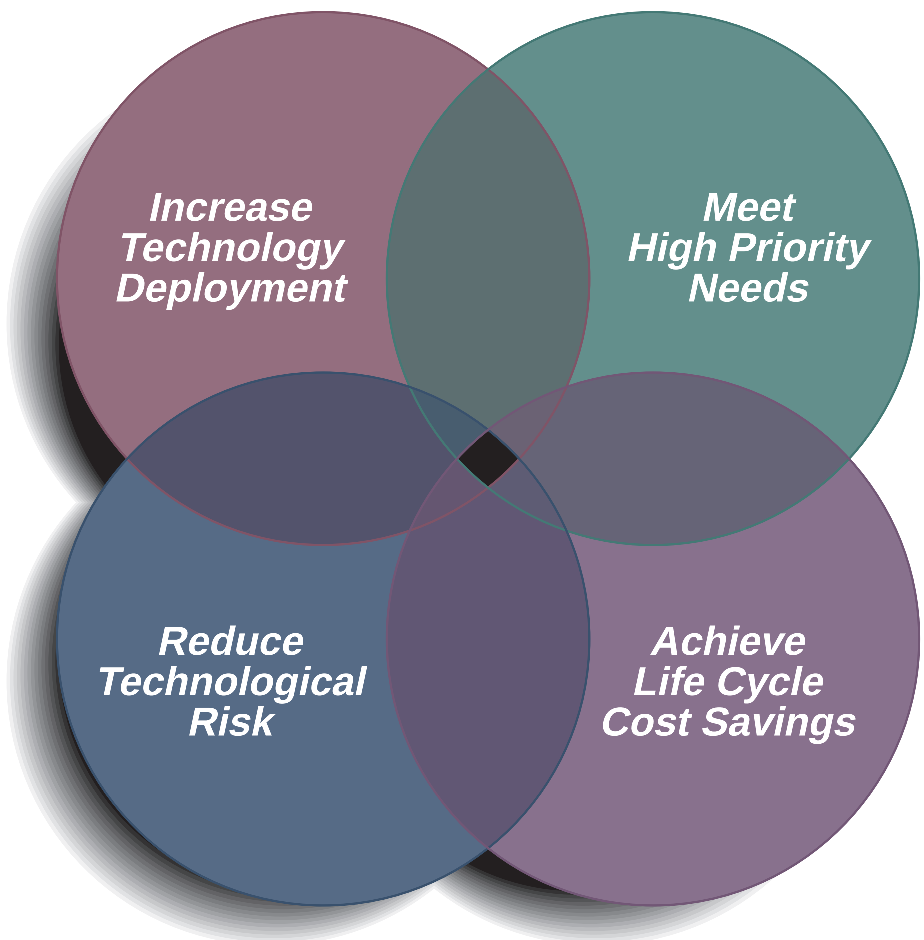


Figure 1-12 Customer-driven performance measures to improve investments management

Key Accomplishments

Environmental technologies from the EQ R&D Portfolio have been developed and applied to solve environmental problems and prepare for disposition of waste and materials in a geologic repository. This section presents highlights of these technologies, organized by the problem area or process steps. In many cases, ongoing R&D continues to enhance the effectiveness or the scope of application of these technologies. More detailed accomplishments are provided in Chapters 3 through 9.

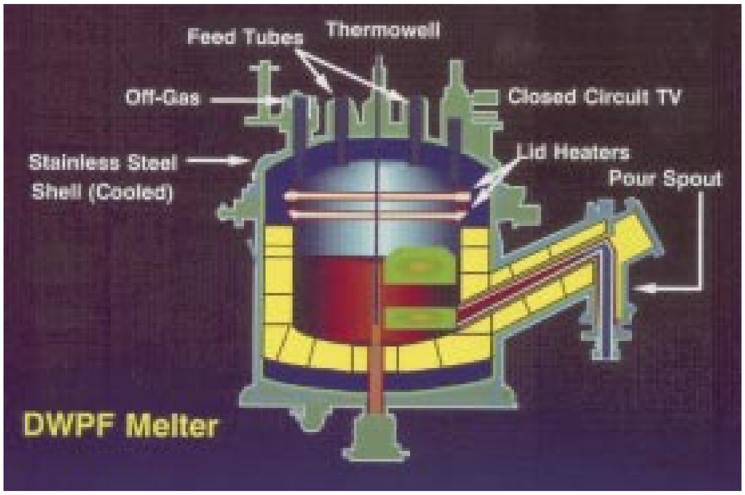
Characterization

Numerous improvements in instruments have been achieved, including portable detectors and nondestructive and nonintrusive examination techniques for both stored waste and materials and for contaminated surfaces and soils. Robots and tele-operated vehicles are now in use for facility and storage tank inspection. Collectively, these advances enable a better understanding of the characteristics of the hazardous wastes and materials to be managed while reducing the worker exposure to these materials. Several technologies, such as portable chemical sniffers and nonintrusive spatial metal detector arrays, have been adapted and used by other agencies for applications as bomb, drug, and weapons detectors.

Houdini vehicle working by remote operation in a tank.

Treatment, Volume Reduction, and Pollution Prevention

Chemical separation technologies for the removal of selected metals and radionuclides have already reduced life-cycle cleanup costs by over $6 billion. Technologies to minimize pollution by reducing waste volumes and separating out hazardous constituents have also been put to use. Examples include sizing, super-compaction and incineration.



Waste Stabilization

A number of techniques have been fielded for stabilizing material and waste forms to immobilize hazardous constituents and reduce their long term environmental impacts. Different techniques are available for application according to the level of hazard involved. Specific examples include grouting, macroencapsulation, and microencapsulation of low-level, mixed, and transuranic wastes, calcination and vitrification of high-level waste, ceramification of several waste types, safe dry storage of spent nuclear fuel, and caps and barriers for in situ containment of subsurface contamination. While all of these techniques are in use, many are still undergoing continuing development to improve and expand their application.

Deactivation and Decommissioning

Dozens of new techniques have been successfully applied to achieve deactivation of unique large scale facilities such as the Hanford C Reactor (a plutonium production reactor) and the Waste Calcine Facility, along with complete D&D of multiple smaller test reactors, storage tanks, and laboratory facilities.

Reactor Deactivation: Before and after pictures of the C Reactor at Hanford; the first production reactor to be addressed

Transportation

Achievements in transportation include the development of unique shipping casks and packaging systems for radioactive and hazardous materials. These systems allow the safe transport of materials and waste and have an excellent performance record. No major release of radioactive materials has ever occurred during transportation. When accidents have occurred, typically the greatest environmental impact has not been from the radioactive cargo, but from the diesel fuel of the transport vehicle.

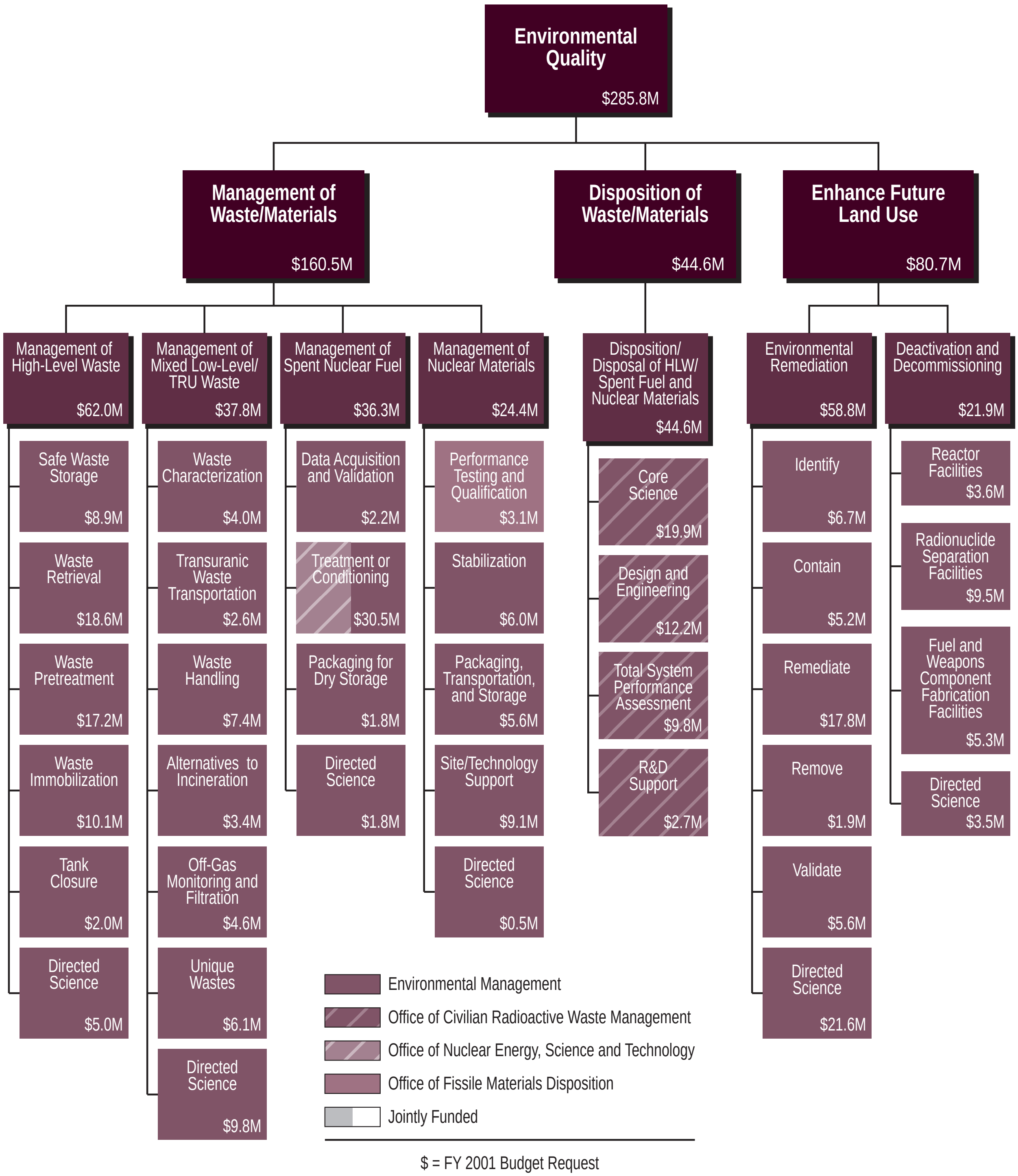
Disposal

The largest R&D efforts for safe waste and material disposal are the geologic repositories for transuranic wastes and for spent fuel and high-level wastes. The Waste Isolation Pilot Plant (WIPP) is now opened and receiving TRU waste. A viability assessment of the candidate Yucca Mountain site as a repository for spent fuel and high-level waste has been completed. Other accomplishments include development of improved radionuclide transport models, installation of unique drift-scale thermal and hydrologic tests at the site, and development of complex engineered barrier system design concepts using material capable of lasting thousands of years. Numerous government and commercial shallow land disposal facilities have been constructed and placed in use supported by technologies developed by the Department.

Environmental Remediation

Successful remediation of over 50 contaminated sites has been achieved through use of innovative technologies including chemical washing, in situ bioremediation, vapor extraction, and the treatment of nonaqueous phase liquids.

Chapter 2
Portfolio Analysis



Chapter 2

Portfolio Analysis

Table of Contents

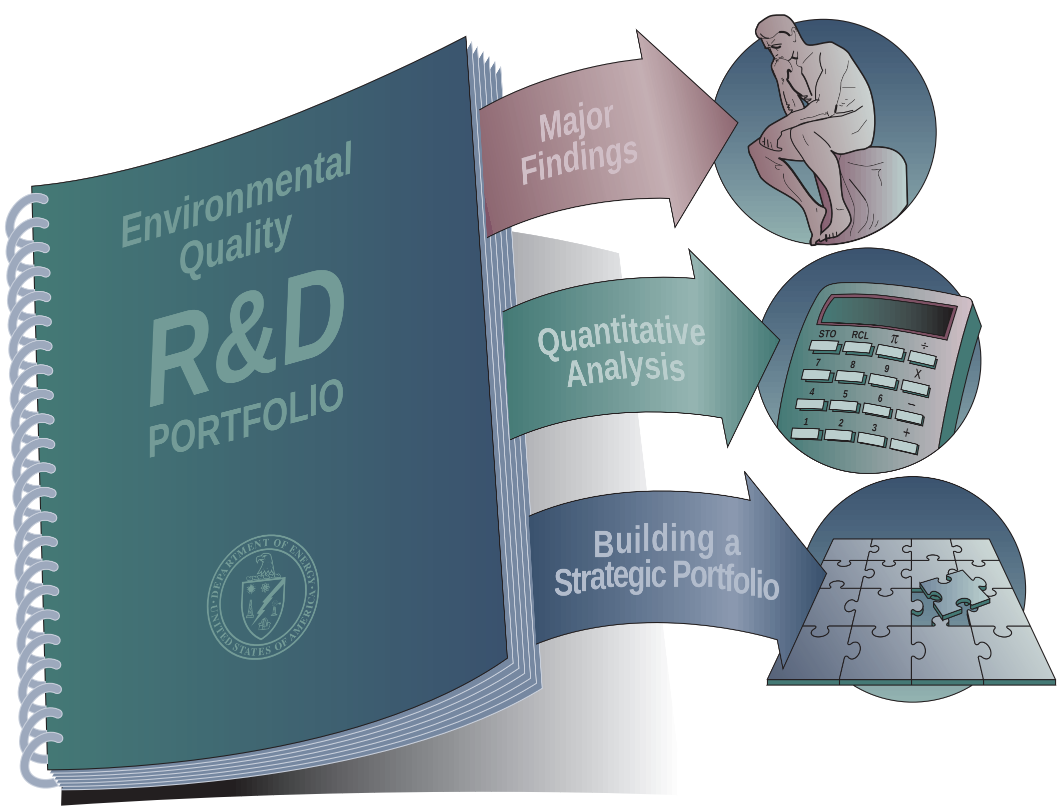
Introduction

This is the first time the Department has attempted to describe and analyze our R&D investments by business line. The effort has been both productive and informative. The process has cut across normal program lines and identified areas where improved coordination can improve the management of R&D and has identified gaps in the investments currently planned. In the past each program carefully reviewed and allocated a portion of its budget to R&D. This approach was effective along program lines but will be enhanced by the portfolio planning process from both strategic and crosscutting perspectives.

This chapter provides the first analysis ever conducted of the Environmental Quality R&D portfolio. As indicated in Chapter 1, this is a baseline document describing the current portfolio; it is not a planning document. The next step in the process is to develop a forward-looking planning tool. Our analysis will be presented from the three perspectives shown in Figure 2-1.

Major Findings describe, in qualitative terms, observations and issues that must be addressed. The Quantitative Analysis of the portfolio, performed on a first-order level, provides a picture of *what is*. Because this document provides a baseline and not a plan, the quantitative analysis will not present a comprehensive description of *what should be*. The final perspective, Building a Strategic Portfolio, is a discussion of the vision of what the portfolio could evolve into, describing *what could be*. It is important to remember that though this portfolio describes the complete Environmental Quality research and development enterprise, the activities are not managed as an integrated investment.

Figure 2-1 Three perspectives of the Portfolio Analysis



Major Findings

A variety of individuals and organizations reviewed the portfolio during its various stages of preparation. These reviews [1], both internal and external, identified a number of similar issues and observations. The majority of these can be grouped into five major findings, and are the first of the three analysis perspectives discussed in this chapter.

Major Finding 1

The portfolio is strongly tied to the Department's current objectives in Environmental Quality. The portfolio is aligned with, and highly focused on, meeting complex-wide cleanup goals and achieving the safe disposition of commercial spent nuclear fuel.

Discussion:

- The portfolio structure is consistent with the major problems associated with the cleanup effort. Within existing funding constraints, investments have been distributed in a rational and defensible manner.
- The research and development activities are developed, approved, and supported by the customer. This strong tie between the customer and the portfolio participants means that the outputs from the vast majority of the portfolio investments will be used.
- The current portfolio structure is generally broad enough to cover the full range of DOE cleanup activities as well as those of selected private sector activities (e.g., commercial reactor decommissioning).

Major Finding 2

The portfolio participants are diverse and distributed, and the portfolio is leveraged. The portfolio has been strengthened through the diversity of participants (universities, laboratories, site contractors, and industry) and the leveraging of activities with both internal and external participants.

Discussion:

- The portfolio's activities are distributed over a wide range of participants from federal laboratories, universities, site cleanup contractors, and industry. The distribution of the participants is consistent with the needs and characteristics of the various stages of maturity and of the portfolio areas. That is, there are investments that both require and have participants from all four major entities: universities, laboratories, site contractors, and industry.
- The portfolio identifies leveraged funds with research activities in the Department's other portfolios, with other Federal Agencies, international organizations and institutions, and with the private sector. Many of these activities and associations are formal in nature. These structured

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[1] Departmental review includes the Undersecretaries Office, the DOE Research and Development Council, the Offices and Programs of the Environmental Quality Business Line and the Office of Science. The Environmental Management Roadmap Core Team (which includes laboratory and M&O contractor personnel), the Environmental Management Advisory Board and members of the DOE Strategic Laboratory Council have also reviewed this portfolio.

agreements are generally more successful than informal agreements as they require co-funding and work scope commitment from all parties.

Major Finding 3

The portfolio recognizes the need for, and attempts to invest across, a full spectrum of activities ranging from basic research through technology deployment.

Discussion:

- The Department is making progress moving towards full integration of directed science with technology development and deployment activities. The directed science budget is distributed across the problem areas in proportion to the identified needs.
- Funding from the Office of Science is providing a solid basis for the existing business line missions. This funding is focused in general areas such as chemistry, physics, and biological sciences as well as targeted funding in more specific areas such as in situ biological remediation to support the overall mission objectives.
- Investments have been shifting from development and demonstration to include basic research and deployment. The Department has recognized the need to focus both on long-term intractable problems and accelerating technology deployment to reduce cleanup costs now.

Major Finding 4

The overall Environmental Quality portfolio may be under invested to sustain achievement of existing mission objectives beyond the near term, i.e. beyond 2006.

Discussion:

- On an annual basis, the Environmental Quality business line constitutes roughly 40% of the Department's budget. The business line objectives are technically challenging, generally long-term in nature, and costly. Yet the Environmental Quality R&D portfolio represents less than 4% of the Department's R&D investment. Current funding may not adequately support a long-term integrated research program.
- The downward funding trend is incongruous with the upward trend 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.
- To offset the under investment, the Department has made science and technology investments that are heavily weighted towards basic research and the deployment of technologies. The result is a significant under investment in applied research, exploratory development, and demonstration activities. While this approach may meet the short term cleanup mission needs, it is not clear that the current portfolio adequately addresses the Department's longer term (post-2006) problems. Lack of investment in applied research, exploratory development and demonstration activities may limit the Department's ability to capitalize on its science investments for developing full scale, deployable technologies from science innovations.

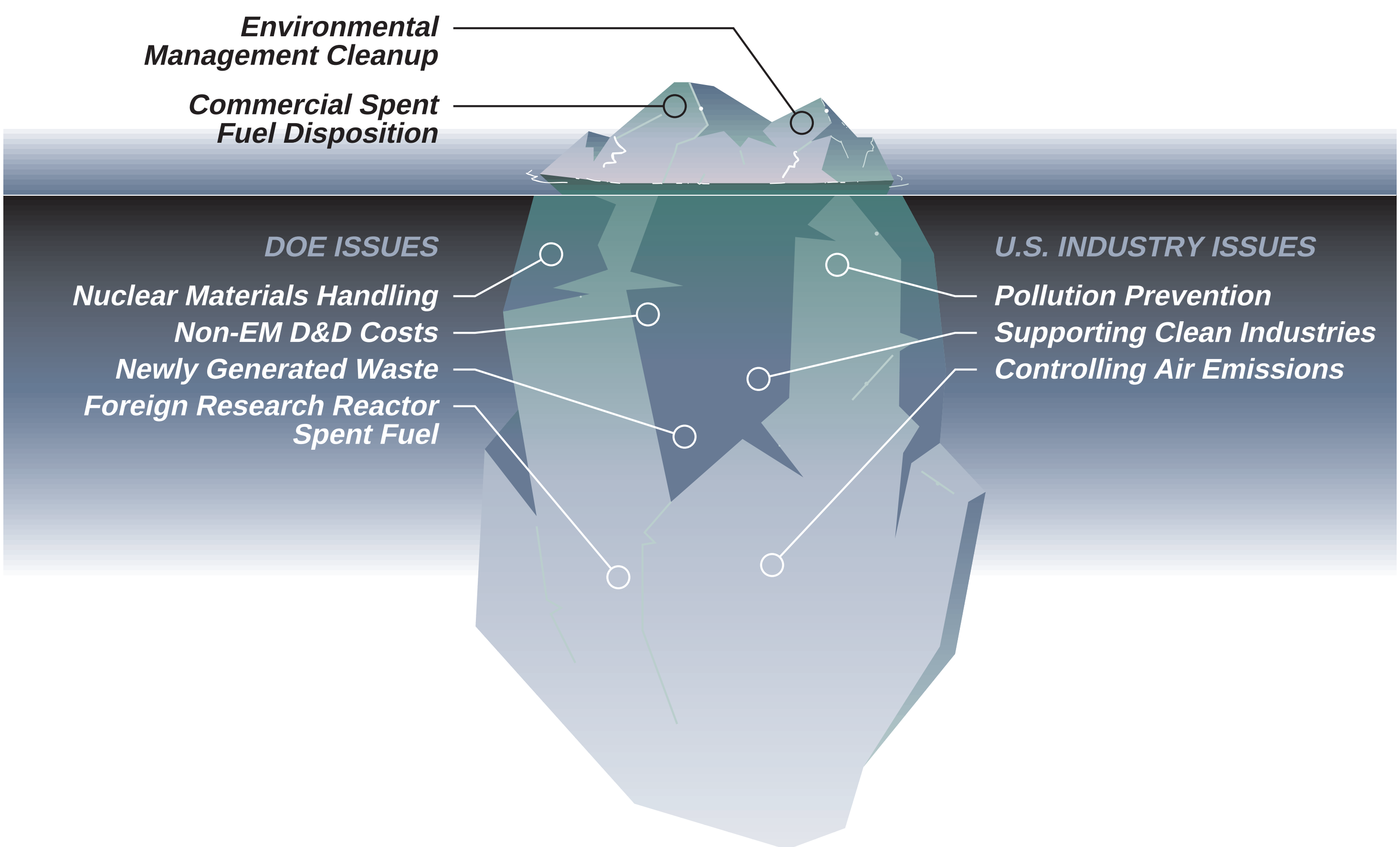
Major Finding 5

The Department should continue the portfolio planning process in order to improve the alignment of the four portfolios and make investment decisions that ensure the Department can help meet the nation's greatest challenges.

Discussion:

- An integrated review of the four business line portfolios should be coupled with the Department's Fiscal Year 2000 strategic planning process. The Department's R&D planning and strategic planning activities should be closely coupled to ensure success.
- The portfolio planning process has already enabled better integration within the individual portfolios. However, because there are significant interfaces and crosscutting elements, each of the business lines will contain some research activities that are relevant to other portfolios. The portfolio management process would benefit from improved coordination and a more integrated approach to these inter-portfolio activities.
- Expansion of the Environmental Quality portfolio will require significant federal and private sector interaction. The use of science and technology roadmaps must be expanded to cover a

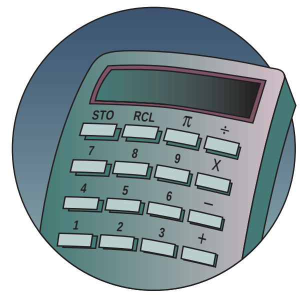
Figure 2-2 The current portfolio is just the tip of the Environmental Quality iceberg



broader set of environmental quality issues. The Department needs to continue to work with industry to identify the appropriate roles and responsibilities each should have in creating and maintaining the integrity of the nation's environmental quality.

Quantitative Analysis

Many factors are considered when distributing the portfolio across investment areas. Defining the "correct" or best portfolio distribution is a complex and difficult task. This quantitative analysis dissects the investments to provide insight into the current investment distribution. The analysis is organized according to the following topics:

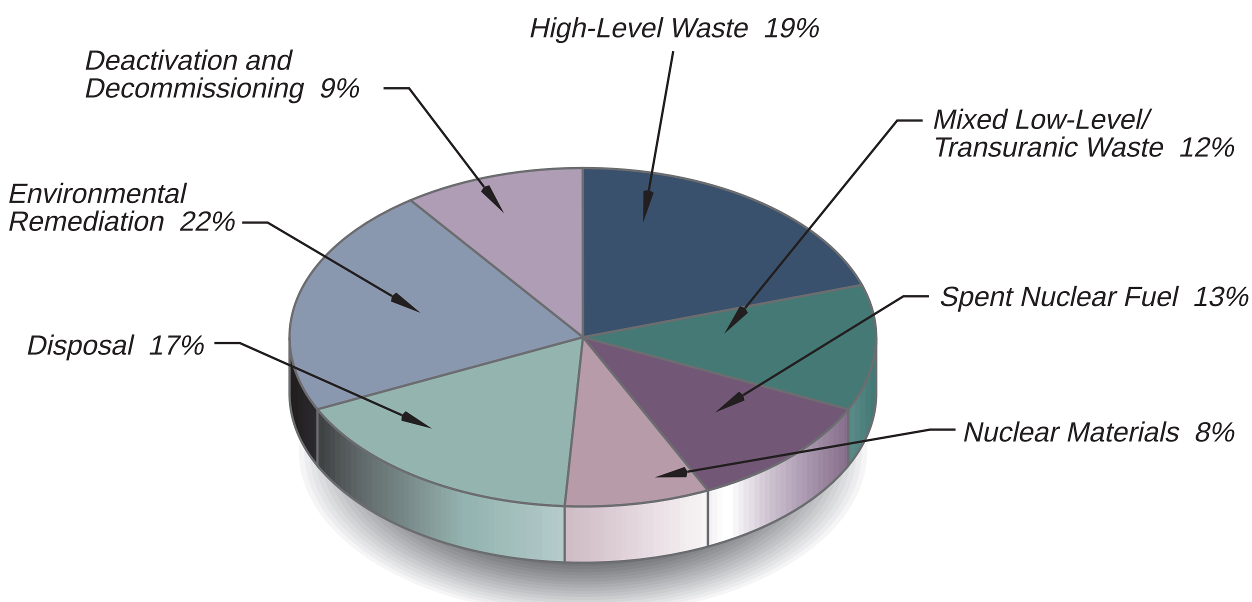


- distribution by investment area—balancing life-cycle cost and programmatic factors,
- investing in research through deployment—a nonlinear approach,
- portfolio participants—strength through diversity, and
- environmental quality—a Departmental investment.

Portfolio Funding Distribution by Investment Area

The majority of the current portfolio has been developed based on current baseline cleanup data. The portfolio distribution (cumulative from FY 1999 through FY 2001) across the investment areas is shown in Figure 2-3.

Figure 2-3 Planned R&D funding distribution by environmental quality/cleanup problem (FY 1999-FY 2001).

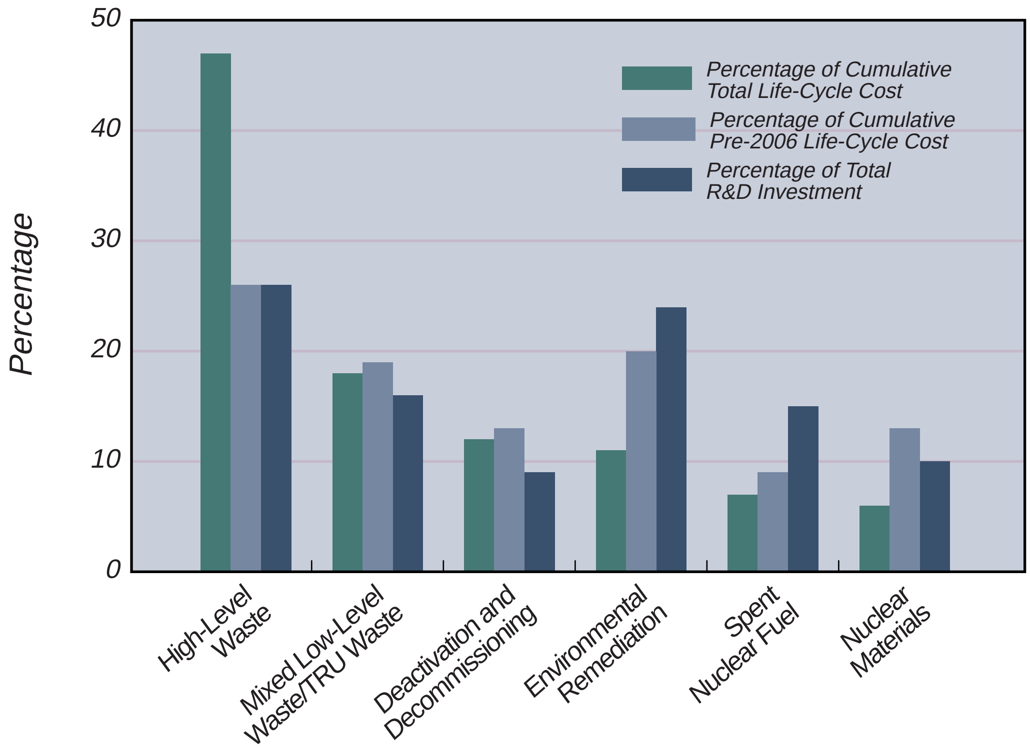


There are two main drivers for this distribution: life-cycle cost and program considerations.

A First-Order Approach: Investing Based on Life-Cycle Cost

A reasonable assumption is that the greatest potential for cost savings is in the areas that have the greatest life-cycle costs. Thus, a reasonable first-order approach is to prorate R&D funding by the life cycle cost of each investment area. For example, the high-level waste life cycle cost represents 47% of the total cleanup life cycle cost. Under this approach, 47% of the R&D investment would be placed in the high-level waste area. Figure 2-4 shows by percentage the pre-2006 and total life-cycle costs and the corresponding R&D investment.

Figure 2-4 Life-cycle costs of investment areas for weapons complex cleanup



While the correlation of investment with pre-2006 life-cycle cost is relatively strong, there are exceptions. For example, over half the total life-cycle cost for environmental remediation is expected to occur before 2006. To reduce cost, new technologies must be developed and deployed in the near-term. Thus there is a higher investment in this area than would be expected. Environmental Remediation must also address a more distributed and diverse set of problems than the other problem areas and thus receives a higher percentage of funding. In addition, the relatively large investment for Spent Nuclear Fuel is driven by a full-scale demonstration project at Argonne National Laboratory-West, which skews this percentage upward.

Investment Area Programmatic and Milestone Considerations—Meeting High Priority Needs and Reducing Risk

Baseline life-cycle cleanup information and data provide a projection of the technical scope, cost and schedule required to complete cleanup at the Department's remaining sites. The cost, scope and schedule projections are based on the cleanup "end state" that has been identified for each site. As cleanup baseline information and data concerning needs and technology risk are refined it is factored into R&D work packages. Thus programmatic factors contribute directly to prioritization of research and development work packages and the subsequent distribution within portfolio investments.

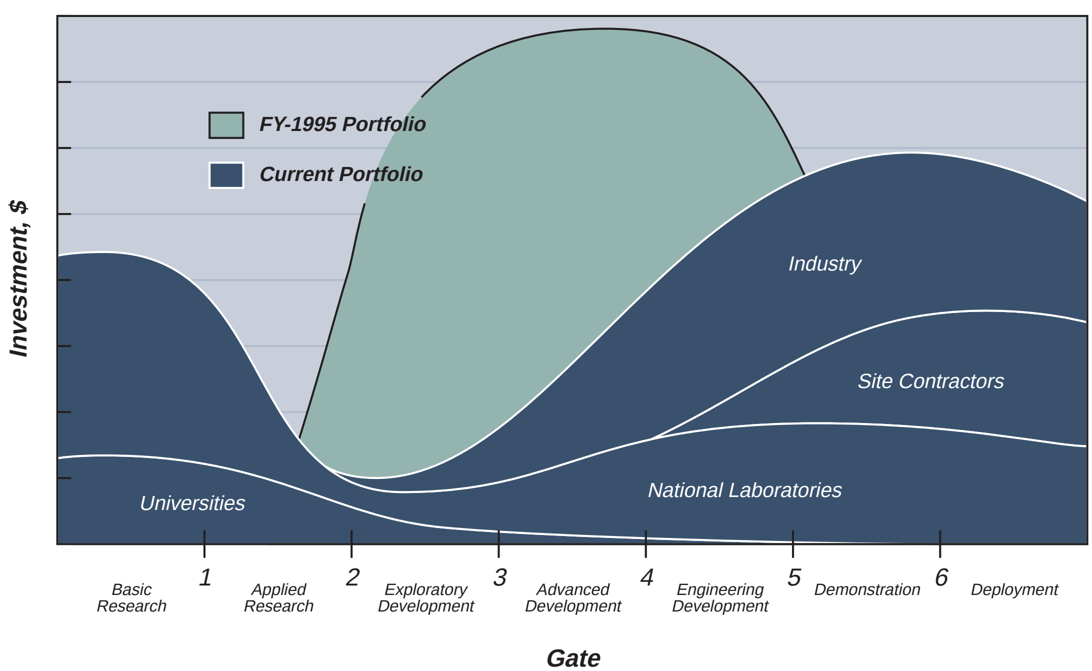
The distribution of investments across the problem areas represents one dimension of the portfolio. Figure 2-5 illustrates a second dimension of the portfolio; the distribution of investments from research through deployment.

Figure 2-5 Multiple Dimensions of Portfolio

Investing in Research through Deployment

As the Department's cleanup efforts have progressed the magnitude and complexity of the problems have become more clearly defined. The initial portfolio approach, focused on technology development and demonstration, was based on a cleanup picture that was still developing. The current portfolio embraces research through deployment with the recognition that we must balance the immediate needs of compliance-driven activities with solutions for the longer-term and more expensive problems. The current portfolio distribution across research, development, and deployment and the shift in distribution are illustrated in Figure 2-6.

Figure 2-6 Investments across the research-deployment continuum



To successfully execute the optimal development of the portfolio investments illustrated in Figure 2-6 an *increase* in the portfolio funding may be required. That is, a critical level must be maintained across the technology maturity spectrum to maintain a science-technology infrastructure capable of supporting effective research and carrying scientific breakthroughs and knowledge through to deployable technologies. Attempting to shift the focus of the distribution while decreasing the overall budget is problematic. Decreasing R&D investments based on near-term progress as evidenced by closing the smaller cleanup sites, is being reviewed. Cleanup of the remaining sites, many with intractable problems, may require greater effort and investment to solve than was initially thought.

Table 2-1 Choosing between the linear and nonlinear models

One analytical tool in portfolio management is the maturity gate model. The model describes a linear progression from basic research through deployment. A technology passes from one stage to the next as it satisfies certain criteria and passes through the next maturity “gate” (hence the name). This model has been validated by experience in industry and in some federal research and development efforts. Money can be saved by testing hardware and/or processes at pilot, bench and demonstration scales before deciding to proceed with deployment. The model works well in these well-defined and controlled situations.

However, the cleanup program requires solutions that go beyond the development of a specific piece of hardware or process. In these instances the linear model is not always applicable. The exceedingly complex nature of the cleanup problems makes solution development an ongoing process. For example, during the deployment of a solution to a remediation problem we find that additional fundamental knowledge, such as reaction rates or partitioning coefficients, is required. Directed basic research must be provided to support the deployment of the solution. Research and development in an environment like this requires investments that support each phase: research, development, demonstration and deployment. This model is nonlinear. Investments may be required simultaneously at different gates, and the results of all these investments must be integrated. Investment decisions based on this nonlinear model are often different from those based on the linear approach.

Portfolio Participants—Strength through Diversity

A portfolio that invests in science through deployment must have the involvement of universities, national laboratories, site contractors, and industry. This helps maintain balance by ensuring participation from contributors whose main focus and background represents each segment of the technology maturity continuum. For example, universities provide a basic and applied science perspective whereas industry focuses on demonstration and deployment. This diverse and highly distributed, national and international “team” is difficult to coordinate and integrate—but this diversity and complexity is essential to provide the “cross pollination” and infusion of different perspectives and insights required to solve complex cleanup problems.

The participants in this portfolio are diverse and distributed; the mix of people, companies, organizations, and institutions that execute the EQ R&D portfolio activities are funded in proper proportions consistent with current investment strategy. Funding and integration of the appropriate participants at each stage of technology maturity, as illustrated in Figure 2-7, has been achieved within the constraints of current funding.

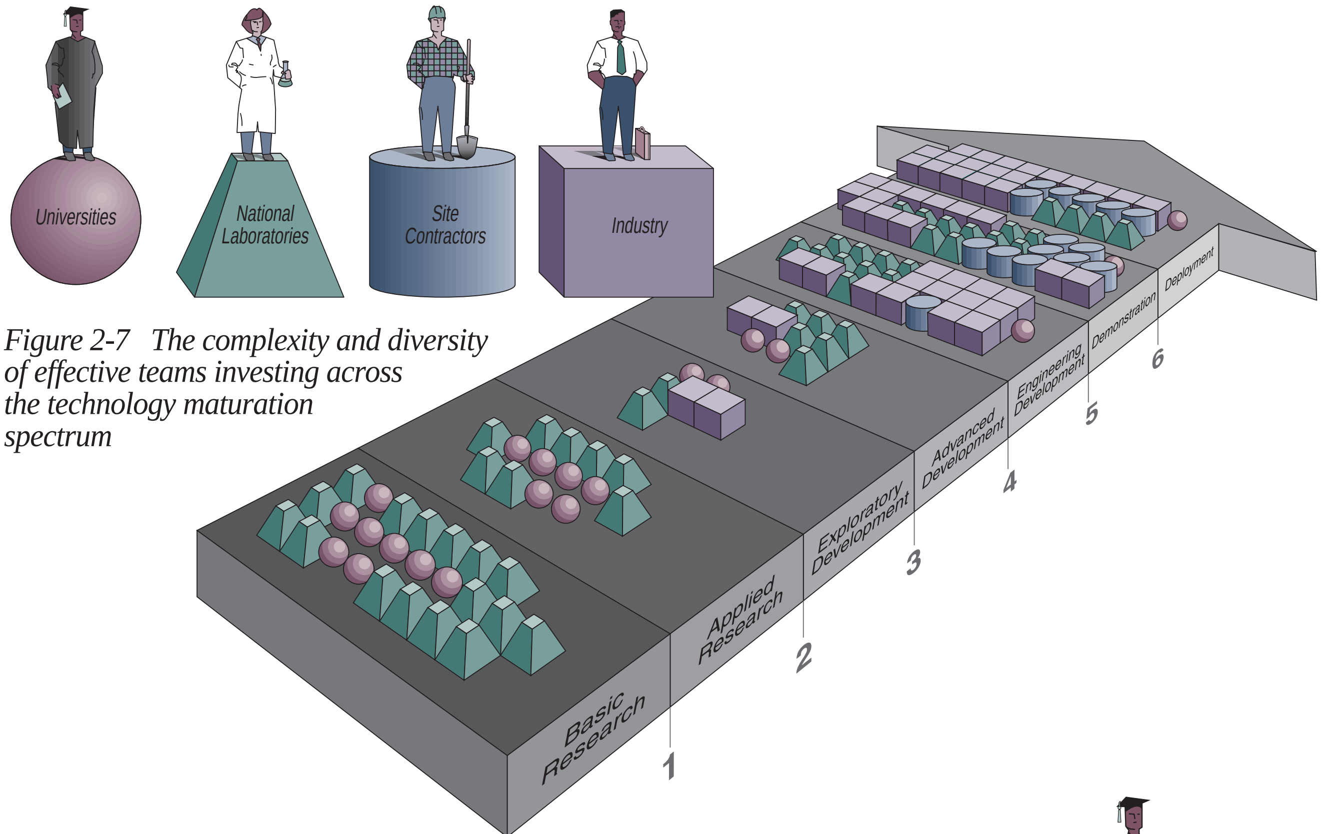
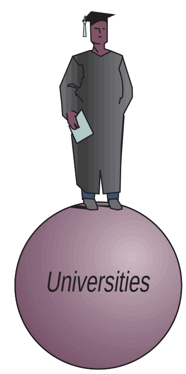


Figure 2-7 The complexity and diversity of effective teams investing across the technology maturation spectrum

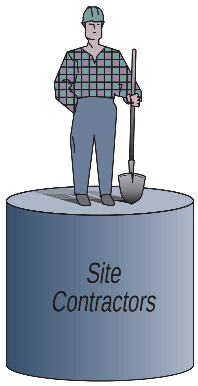
Universities



The Nation's colleges and universities provide an extremely valuable reservoir of science and technological expertise. The breadth of science and technology expertise of these institutions complements the depth of the Department's national laboratory system. While only about eight percent of the portfolio is actually conducted at universities, the graduates of these institutions are a major source of technical and scientific personnel entering the laboratory system.

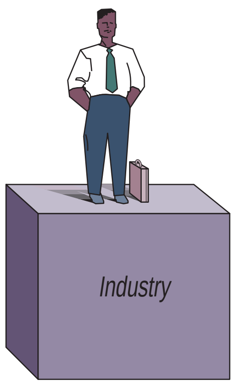
National Laboratories and Federal Facilities

The national laboratories and federal facilities provide a significant portion of the publicly funded scientific and technological infrastructure of the United States. A number of special and unique capabilities and resources exist within this laboratory and facility system that are essential to achieving the cleanup mission. The hot cells and canyons for handling and manipulating highly radioactive materials are unique. These are the only facilities capable of demonstrating and testing technologies that treat or handle high activity sources. Another resource the laboratories and facilities provide is a test bed where demonstrations on "hot" or contaminated materials can be conducted within regulatory constraints and permits.



Site Contractors

The site contractors provide critical operational expertise and in-depth understanding of the challenges associated with the cleanup tasks. Usually the business lines of large corporate enterprises, they operate many of the unique facilities of the Department's complex and help define and maintain an operating space within the regulatory environment in which to demonstrate new technologies and perform cleanup activities. This ability to provide "test beds" for demonstration projects and to aggressively deploy new technologies is an essential component of the EQ R&D enterprise.



Industry

As development efforts mature and move to demonstration and deployment the activity shifts from the laboratory to the site contractors and industry as the primary performers and partners. As previously noted, the government must support research and development to fill technology voids that the private sector will not or cannot fill. Though both the public and private sector can, and do develop technologies, only private sector companies can commercialize technologies and make them widely available. A significant part of the partnering activities between industry, the laboratories, and site contractors is the attempt to reduce the financial and technical risks in moving environmental technologies beyond demonstration to widespread deployment. Recent efforts in this area have resulted in the commercialization of a large number of environmental technologies. Over 125 companies, located in 32 states and Canada, have commercialized over 140 different environmental technologies. These technologies range from detection and characterization, to remediation and treatment, to robotics, to stabilization and immobilization. The majority of these commercial technologies are being used to support the cleanup mission.

Potential to Leverage Investments with Industry

The investment areas differ considerably in the amount of external investment by industry. The environmental remediation and deactivation and decommissioning investment areas have large industrial counterparts in the United States. The total national site remediation industry is about $6 billion a year, of which the combined contribution of the Department of Energy and the Department of Defense is about $2.8 billion. The deactivation and decommissioning investment area has a

Table 2-2 Private Sector R&D Leveraging is Dependent on the U.S. and Global Market

The 1996 global market for environmental goods and services was about $453B (Environmental Business Journal, 1997). The United States has the largest segment of that industry at about 40%, or $181B. The U.S. environmental industry is composed of two general areas—public infrastructure services (such as potable water, wastewater treatment and municipal waste management) and environmental site cleanup. The latter area grew rapidly in the early 1990's following a period of new and significant environmental legislation. However, growth has slowed and actually decreased over the past five years even though the DOE and DOD remediation expenditures have increased. A characteristic of the industry trend today is a rise in remedial construction as a proportion of total spending while site assessment work has decreased. This trend away from studies and toward actual cleanup is likely to increase.

similar industrial counterpart for the deactivation and decommissioning of commercial nuclear power plants. The potential to leverage R&D investments in these areas is reasonably high.

In contrast to these areas, the high-level waste and transuranic waste investment areas have virtually no industrial counterparts and only limited potential to benefit from external investments. This is because the Department is the sole customer for technology in these areas. Therefore, larger federal investments in these areas are required to achieve comparable technology advancements.

Note that there is a significant contribution made by the commercial nuclear utilities for the preparation of the geological repository that will house the Nation's commercial spent nuclear fuel as well as the high-level waste and spent fuel of the Department. Some of this funding supports current efforts to explore Yucca Mountain as the disposal site.

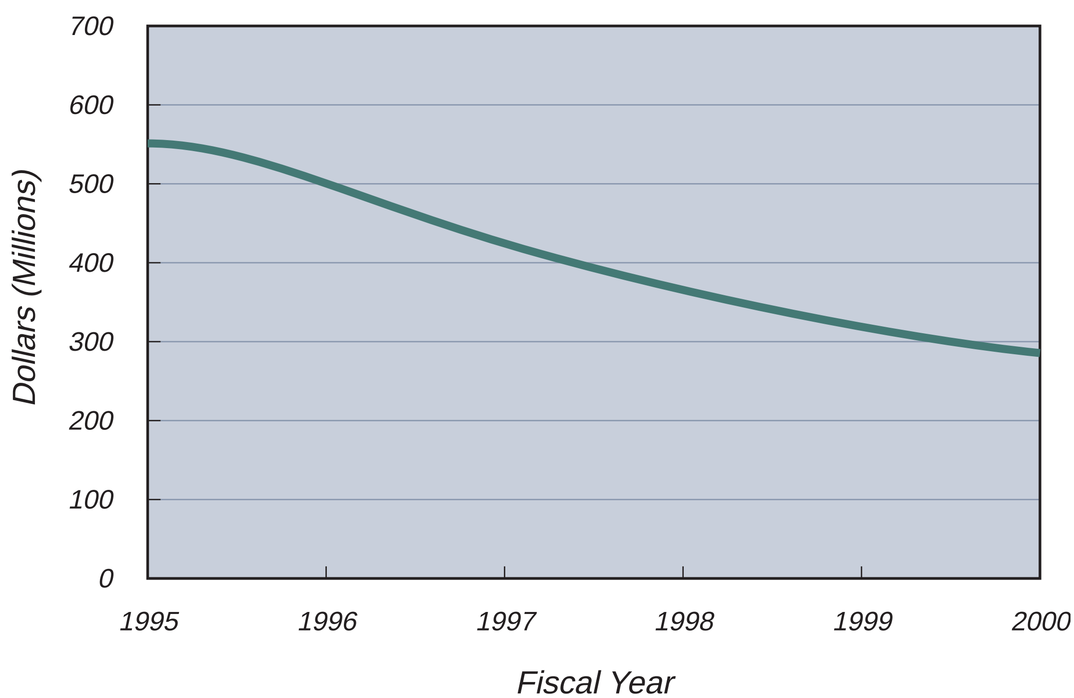
Decline of the Environmental Quality R&D Portfolio

This section of the portfolio analysis looks at the breadth or scope and depth or robustness of the overall investment trend within EQ as well as the trends within selected investment areas. While the Department has only recently started to analyze and manage its R&D activities within the four business line portfolios, it is informative to broaden the trend analysis outside the timeframe of the current portfolio. The trend is downward and approaching a level that may not be able to support an effective, long-term Environmental Quality mission.

Overall Trend for the EQ R&D Portfolio is Downward

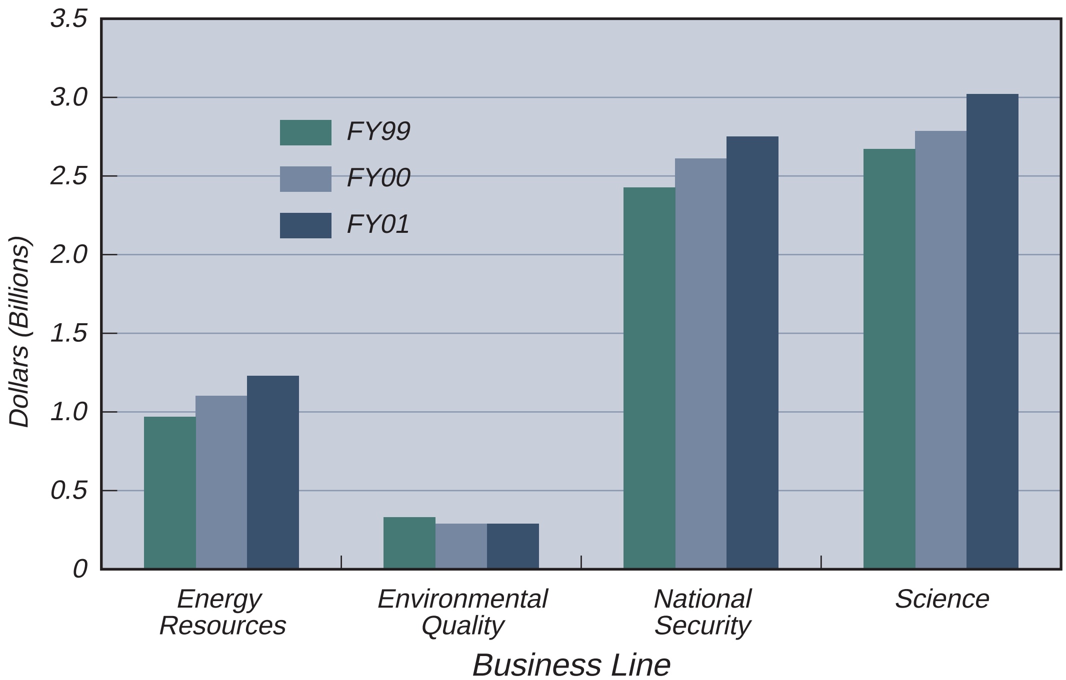
The portfolio, as currently defined by the framework, is estimated to have peaked in the mid-1990s at roughly $550 million and has declined to its current level of about $290 million—a 50% decrease in five years. This decline is depicted in Figure 2-8 and is in contrast to the growing set of needs and issues defined by the cleanup sites that the portfolio must address.

Figure 2-8 EQ R&D Portfolio Funding Trend



The decline stands in contrast to the funding increases shown in Figure 2-9 in the other Department business line portfolios.

Figure 2-9 Business line R&D Portfolio funding levels FY99-FY01



Trends within the Environmental Quality R&D Portfolio

While the overall funding trend for the portfolio has been downward there have been several changes of significance within the individual investment areas. Three-year funding levels (FY99 through FY01) are shown in Figure 2-10. These changes have been driven primarily by progress in the Department's cleanup efforts but also reflect the formation of new offices (e.g., the Office of Fissile Materials Disposition) and changes in Departmental policy (e.g., acceptance of foreign research reactor spent fuel).

Over the last few years the portfolio has invested heavily in solving problems associated with mixed waste and contaminated soil and groundwater. In the mid-1990s each of these investment areas received roughly $100 million a year. These large investments were driven by regulatory milestones in Federal Facility Compliance Agreements. That is, a large number of records of decision had to be made for mixed waste treatment and environmental remediation. To best prepare, the Department tried to prepare a range of technical options. In the year 2000, the mixed low-level waste investment will be under $40 million and environmental remediation will stabilize at around $60 million per year. Environmental remediation research and development is continuing despite active remediation. This is primarily due to the need to reduce the costs of long-term environmental stewardship and provide options in case of near term failure of remedies already selected. A concern in this area is the relatively large decline in recent years of external investments in environmental remediation, making it increasingly difficult to leverage the portfolio's investments.

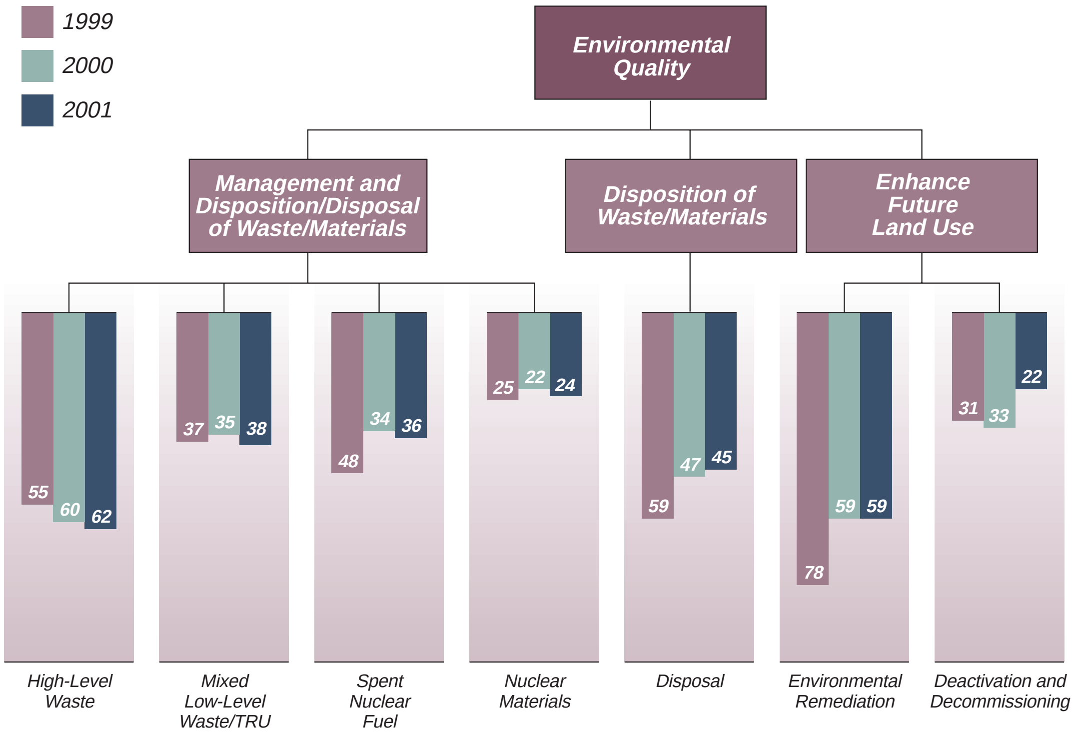


Figure 2-10 Three-year funding levels and trends

The trends within the portfolio reflect efforts to balance multiple priorities. While the Department aggressively pursued improvements in the treatment of mixed waste and contaminated soils and groundwater, there were smaller but steady investments in the longer term and higher cost cleanup efforts associated with the management of high-level waste and the management and disposal of transuranic wastes. Note that the R&D associated with the disposal of high-level waste is included in the disposal section. Technical uncertainties and costs associated with high-level waste and transuranic waste dominate the Department's cleanup profile after 2006.

The trend in D&D funding is sharply downward in direct contrast to the increasing need in the commercial sector for D&D technologies. A commitment to a longer-term view would provide the basis to achieve considerable leveraging with the private sector, which would be mutually beneficial.

Research and development funding for disposal is slightly downward, reflecting the progress achieved toward reducing uncertainties on long-term performance of disposal systems. The funding in this area is expected to continue to decrease as the program moves to submission for licensing and subsequent construction and operation.

Funding decreases justified on the basis that cleanup is progressing and the 2006 cleanup mission is partially complete ignores the fact that costly, difficult and complex cleanup problems have not been addressed. It is likely that R&D funding as a percentage of EM's annual budget, may have to actually increase to solve the remaining technically complex and difficult challenges. Increased funding would also allow parallel development of alternatives, which can minimize the risk of failure of single point-solutions to large, expensive projects. Experience with several large remediation projects such as Pit 9, In-Tank Precipitation, etc., highlights the need to invest in alternative approaches and technologies.

Understanding the Department's Investment in Environmental Quality

With the exception of the Science R&D Portfolio, there are multiple participating programs or offices within each business line portfolio, . The relative size of individual program contributions to the portfolios and the relative size of each portfolio are illustrated in Figure 2-11.

Funding for the EQ R&D portfolio for Fiscal Year 2001 is $280 million. This investment is roughly 4% of the Department's overall research and development investment and makes the portfolio the smallest of the four business line portfolios (Figure 2-12). While Environmental Management and the Office of Civilian Radioactive Waste Management (the major contributors to the portfolio) make up roughly 40% of the overall Department budget, a relatively small share of that budget is devoted to R&D (Figure 2-12).

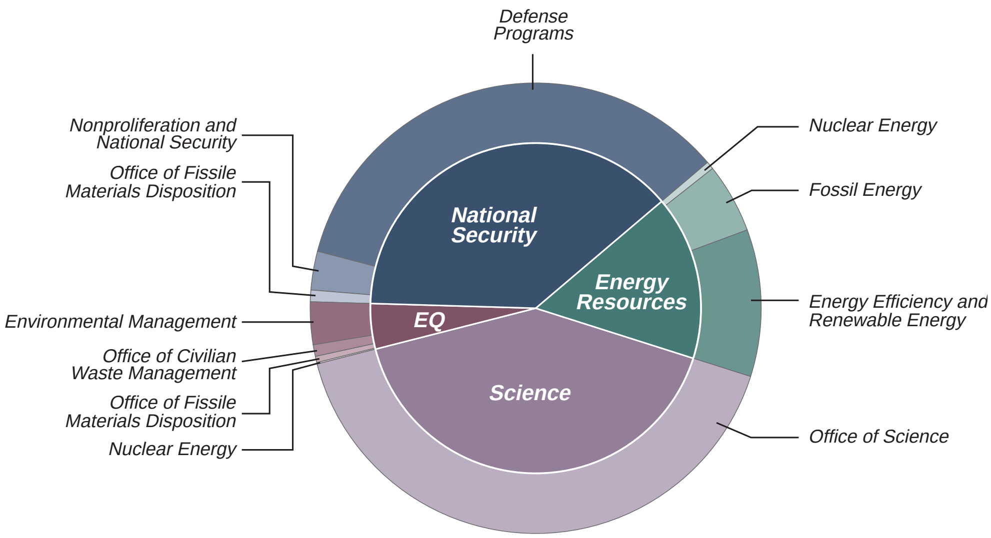


Figure 2-11 Relative size of Business Line R&D Portfolio Budgets and Business Line Participants

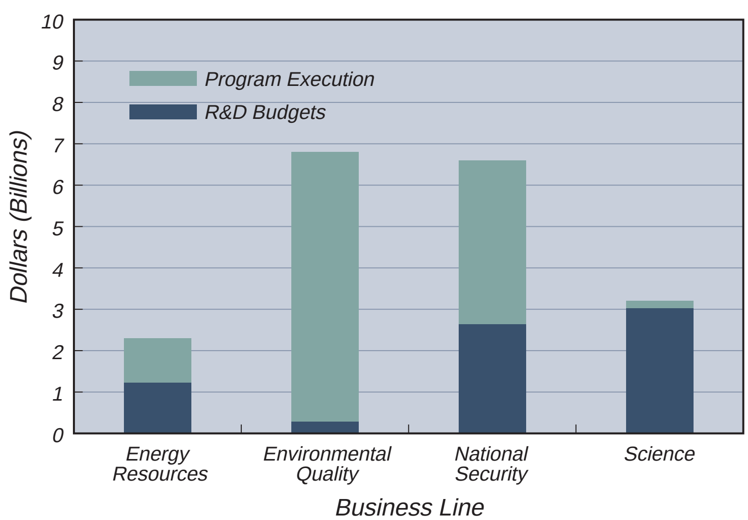
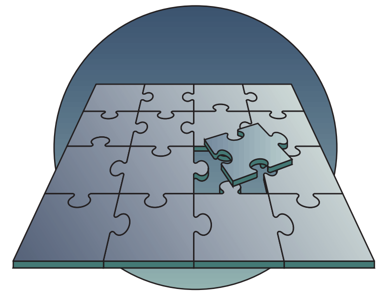


Figure 2-12 Relative size of Business Line and R&D Portfolio Budgets

Building a Strategic Portfolio



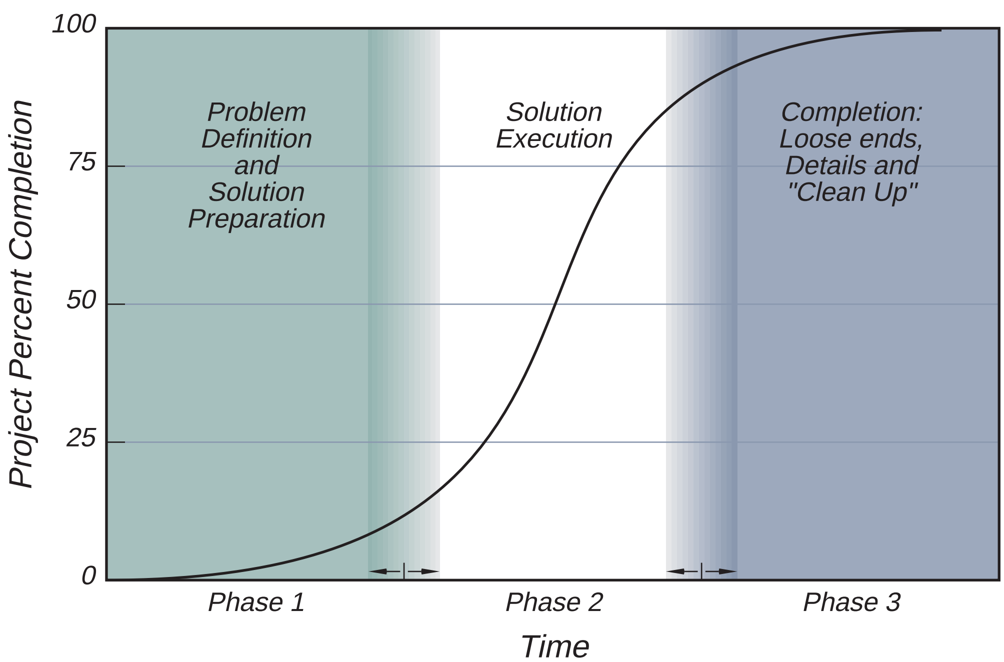
The direction and evolution of the Environmental Quality R&D portfolio will occur within two major contexts. The first context is the existing investment framework; the narrow, highly focused effort to meet the challenges of the nation's nuclear legacy. Incremental, evolutionary change will occur as the portfolio responds to the changing nature of the cleanup mission. Leveraging the Department's investments to encompass the broader range of specific national environmental challenges creates the second context. The response to this challenge may require a revolutionary, rather than evolutionary change in the portfolio framework.

Incremental, Evolutionary Change—Focus on Supporting Cleanup

The life cycle of individual cleanup activities and of the cleanup program in aggregate can be characterized by three general phases. The primary science and technology needs of each phase are different. The research and development investments supporting the program must also reflect those changing needs. An understanding of the current state and rate of progress of the cleanup program is fundamental to planning future R&D investments.

The three phases, illustrated in Figure 2-13, are: problem definition and solution assessment and preparation; solution execution; and completion. The first phase includes defining the problem as completely as possible, identifying a set of potential solutions, selecting the best solutions, and assembling or constructing the necessary tools, hardware and processes to implement the solution. In the second phase the primary solutions are executed. Most of the visible progress of the activity or project occurs during this phase. Typically 80 to 90 percent of the project objectives are achieved

Figure 2-13 The three phases of program and project activity



during the second phase. The final phase completes the final details and "loose ends" that arose during the second phase. Details and loose ends include the minority wastes, materials, and other exceptions that were not amenable to the primary solution due to some special characteristics (physical, chemical, political, etc.). The final phase also includes cleaning up and putting away the tools (e.g., facilities and hardware) used to execute the solution.

The science and technology required to support each phase is different. The first phase requires a solid scientific basis in order to completely characterize the problem and a strong technology base from which to draw alternative solutions and optimize the solution path. Science and technology roadmapping is an important tool to be used during this phase to analyze the maturity and robustness of the science and technology supporting this phase. Research and development investments must be sufficient to maintain the supporting scientific and technological infrastructure. Investments across the full research-deployment continuum are needed, although additional emphasis must be placed on research and on the development and demonstration portion of the continuum to support this phase. In the solution execution phase science and technology support focuses on improvement of operational efficiency and the support required to solve the inevitable problems that escaped identification in the first phase. Again the entire research-deployment continuum supports this phase, however additional emphasis is required at the beginning and end (research and deployment) of the continuum to improve understanding of the problems that arise and provide the technical support to deploy technologies in a way to resolve these problems. The final phase is characterized by the need for better definition of the special problems remaining and identifying new solutions. The problems remaining in the third phase represent only a small portion of the total cleanup problem, but they present the greatest scientific and technological challenges.

The complete cleanup program is comprised of projects that are in different phases of completion. Currently, many small sites are in the final phase, while most of the largest sites are still in the initial phase. Operations for several waste types are underway across the complex, while design and construction of major facilities is underway for other disposition paths. The current portfolio framework is acceptable for developing incremental evolutionary changes to address varying states of program maturity.

Revolutionary Change—A Strategic Portfolio for the 21st Century

As the nation moves into the 21st century it is appropriate to reevaluate the Department's strategic goals and objectives. This is particularly true in the case of the Environmental Quality business line and the nation's environmental challenges. The evolving activities of the current portfolio coupled with known and emerging environmental issues suggests a new framework for the portfolio. The new framework would continue to support the weapons complex cleanup and the disposition of commercial spent fuel, but could do more. The framework could encompass the full range of responsibilities within Environmental Quality—provide the technologies and institutions to solve domestic and international environmental problems. A potential framework is illustrated in Figure 2-14.

This framework is built on four key areas: sustainable development, materials management, resource enhancement, and environmental stewardship. While many of these investment areas are simply an extension or expansion of existing work, some are new. The vast majority will need to be explored

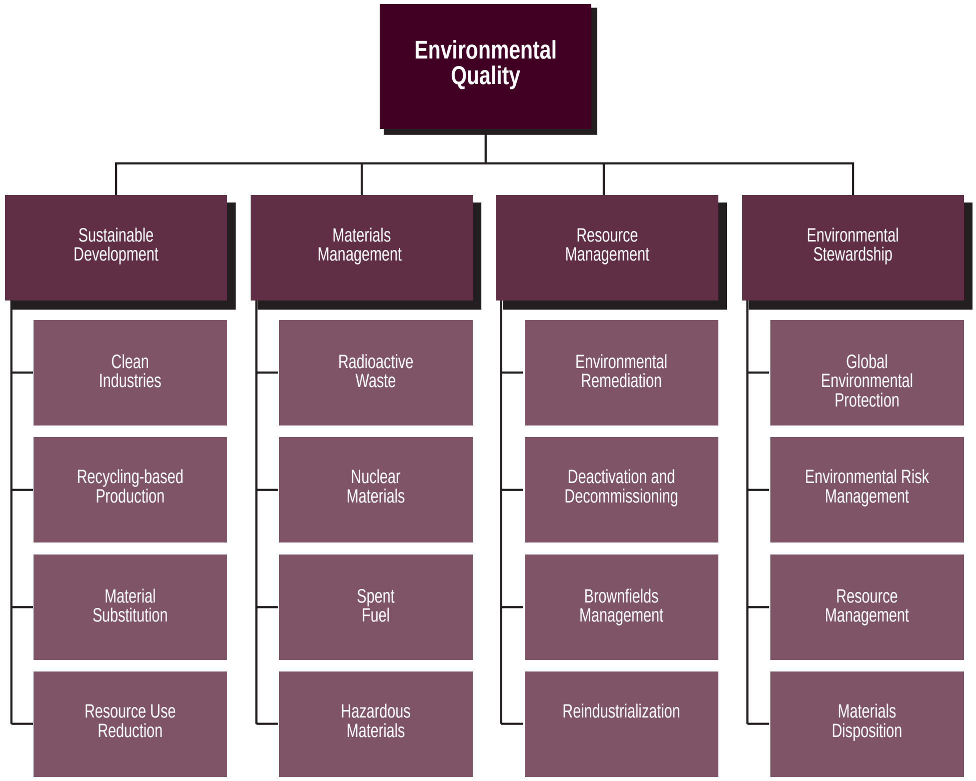


Figure 2-14 A Potential Environmental Quality Portfolio Framework for the 21st Century

and refined through the Department's strategic planning process. A summary of the proposed framework is provided in the remainder of this chapter.

Sustainable Development

Achieving sustainable development requires change to occur in a number of areas. Some of these areas, e.g., societal and political, are affected by technological advances but are certainly not driven by them. Within the context of Environmental Quality business line, we are focused on the environmental component of sustainable development.

The Department is currently investing in sustainable development research and development. These investments include: the clean industries component of the Energy Resources portfolio as well as many of the investments aimed at more efficient energy use. There are also a limited number of investments within the current portfolio, e.g., electronics recycling and other pollution prevention activities. However, these investments are limited in scope and may not support the nation's needs into the 21st century.

Additional investments focused on areas such as recycling based production, material substitution and the reduction in use of our nonrenewable resources without sacrificing our quality of life are critical. Increased population growth coupled with higher standards of living are placing an increasingly large burden on our local and global environments. Managing these demands will require scientific and technical advances. We must find a way to invest to make these advances to provide our nation with viable options well into the 21st century.

Materials Management

Investments in the management of waste and materials will continue well into the 21st century. There will continue to be large quantities of radioactive waste. New waste will be produced as environmental restoration activities proceed and facilities are deactivated and decommissioned. Nuclear materials from nuclear weapons inventories will still require safe management and disposition. Management of spent fuel from commercial nuclear power plants, research reactors, navy nuclear reactors, and the Department's production reactors will continue to be the responsibility of the portfolio.

A new addition to the portfolio might be the management of hazardous materials. Current handling and disposal of hazardous materials is expensive and time consuming, particularly for small generators. While efforts to substitute new materials will reduce the number and volumes of hazardous waste streams, this problem is not going away quickly. More effective management of these materials can reduce direct costs and reduce the potential for long term liability.

Resource Management

The Department will continue to invest in R&D to meet environmental remediation and facility deactivation and decommissioning needs. However, the current focus on the Department's liabilities will need to be expanded. Past, as well as some current, solutions to environmental contamination will have limited lifetimes. The use of engineered disposal facilities and caps and barriers to stabilize contaminated soils and groundwater is a valid approach. However, long-term success is dependent on the integrity of the disposal system. While the new systems are better engineered, these systems will ultimately fail and may need to be replaced depending on residual risk.

Large numbers of commercial nuclear power plants and research reactors are scheduled to be deactivated and decommissioned during the first few decades of the 21st century. The cost of these activities will be passed on to the customers of the utilities and the institutions currently maintaining these facilities. A new framework could focus more aggressively on reducing those costs and increasing the safety of the myriad of workers those efforts will require.

Brownfields management and reindustrialization are relatively new approaches but they may increasingly reflect reality as sites are remediated and facilities turned to new uses. Working and living in either close proximity to or within these areas and buildings will require changes in the way we think, dress, and act. If we invest properly, the impact of these changes can be minimized through scientific and technical advances.

Environmental Stewardship

Many aspects of environmental stewardship are just beginning to receive attention. A significant element of environmental stewardship is the long-term stewardship aspect of the cleanup mission.

With respect to the cleanup mission, stewardship has a very specific meaning. Because it is not possible to completely eliminate all the hazards presented by the wastes and materials encountered in the cleanup mission, these wastes and materials are mitigated to an agreed-upon acceptable level reflecting a balance of risk, cost, stakeholder values, regulations and technology capability. It is then necessary to provide an adequate level of protection to human health and the environment from the hazards that remain. For example, we must ensure that disposed or isolated wastes or hazardous materials do not "escape" their protective containment. These activities are called long-term stewardship, and are complementary activities that transition from cleanup without discontinuity. The four phases of cleanup-stewardship are:

- Achieving the best possible end state (based on best available technology),
- Verifying the end state is achieved,
- Demonstrating end state integrity is maintained and predicting and detecting potential end state failures, and
- Quickly and effectively "re-remediating" a failed end state.

The relationship and technology requirements of these phases of the cleanup-stewardship endeavor are illustrated in Figure 2-15. Because this involves activities that have never been done before, there is a high degree of uncertainty. Significant investments in research and development will be necessary to provide adequate support. Environmental risk management, resource management, and materials disposition are all significant elements of long-term stewardship. Each of these has unique aspects that make them separate, significant components of environmental stewardship.

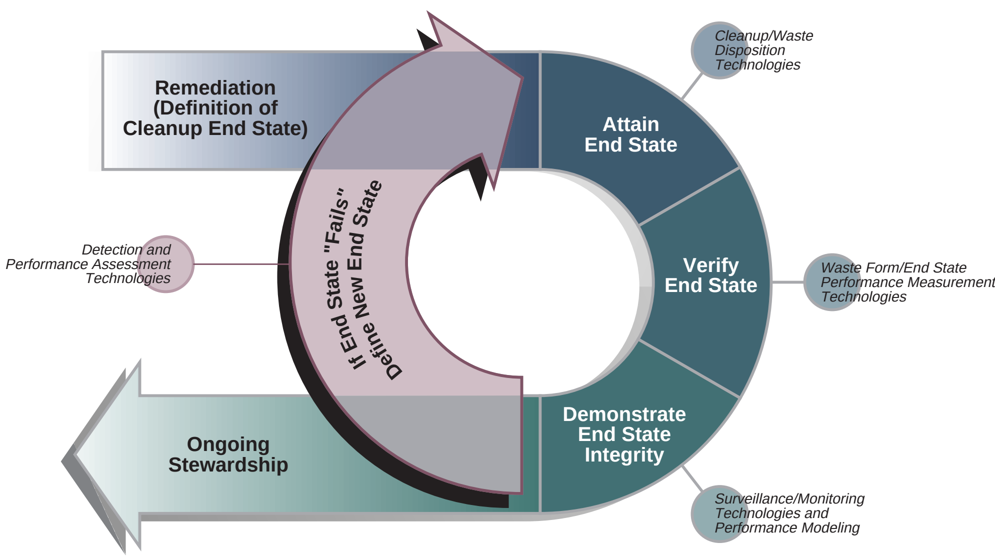
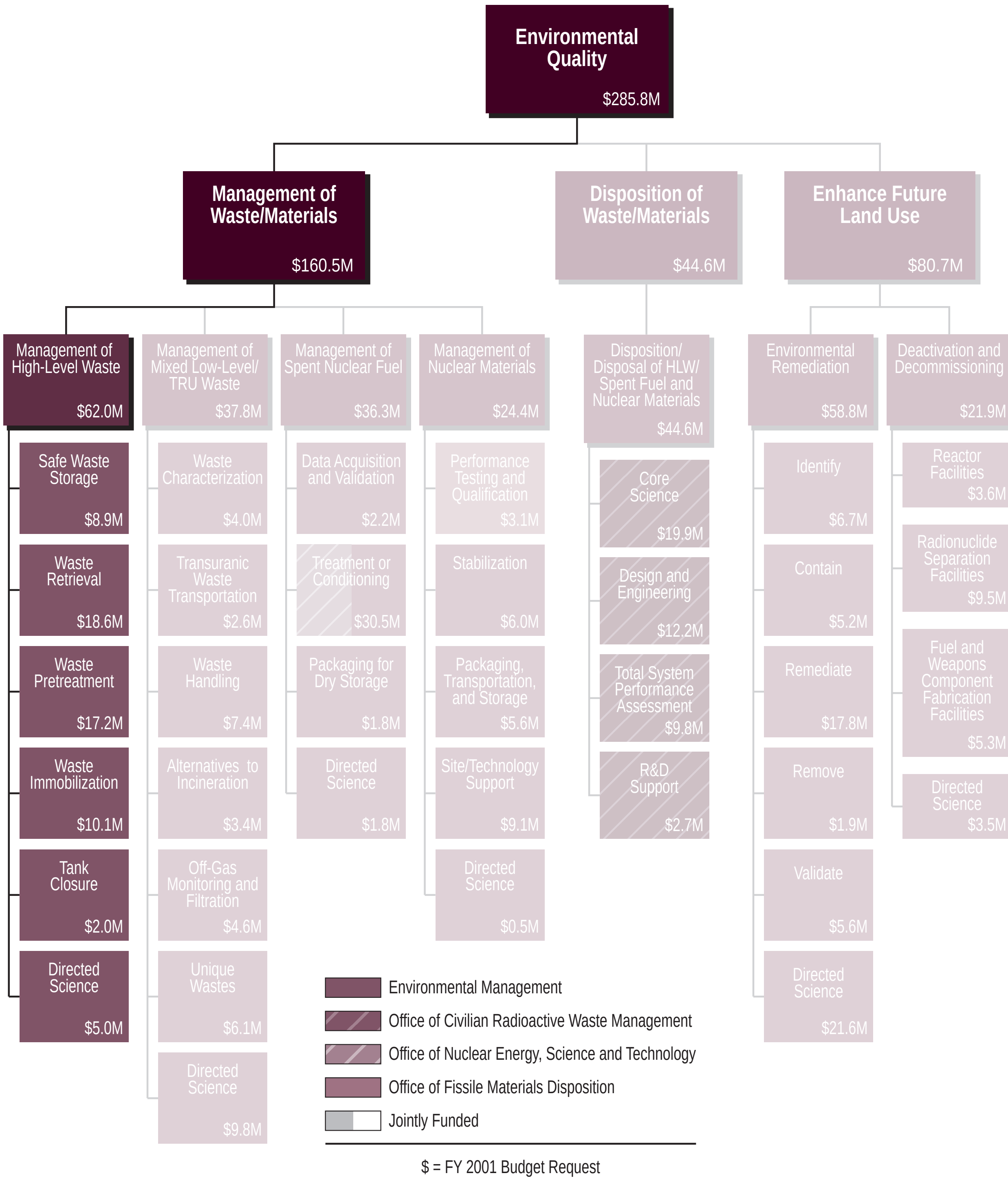


Figure 2-15 Science and technology to support long term stewardship

Long-term stewardship is usually associated with the local or regional environment. However, global environmental protection is an environmental quality issue that affects everyone. In this case stewardship has the more common, broader meaning of exercising responsible care and use of the global environment. Investments are being made by the Department in this area. Within the Science Portfolio we are investing to improve our understanding of global warming. The Energy Resources Portfolio is aimed at reducing the environmental impacts of energy generation and use. Within Environmental Quality we need to look at those research and development activities that can provide better understanding of both the robustness and fragility of elements of the global environment. These investments can support the development and implementation of appropriate national and international agreements and of more environmentally friendly production and economic development.

Chapter 3
High-Level Waste



Chapter 3
High-Level Waste

Table of Contents

Page

Overview

Definition of Problem Area

High-level waste (HLW) was generated during production of nuclear weapons and reprocessing of reactor fuels. There are 280 large radioactive waste storage tanks and more than 63 miscellaneous underground storage tanks across the DOE complex containing over 90 million gallons of radioactive waste. Most of these tanks have exceeded their design life, some have leaked, and all represent significant occupational and public risks. Current site baseline technologies are costly, pose significant programmatic and safety risks, and have technology gaps. The waste is currently stored at five main locations.

- The Savannah River Site (SRS) in South Carolina has 51 underground high level waste storage tanks. Two tanks were closed in 1997. The remaining 49 tanks store about 125 million liters of waste containing approximately 470 million curies (MCi) of radioactivity.

- In Washington State, Hanford has 177 tanks that store 208 million liters of waste containing about 200 MCi of radioactivity.

- The Idaho National Engineering and Environmental Laboratory (INEEL) has 11 tanks with 5.3 million liters of liquid waste containing 0.5 MCi of radioactivity. In addition, 3.8 million liters of dried calcined waste with approximately 24 MCi of radioactivity is stored in seven bin sets.

- The Oak Ridge Reservation (ORR) in Tennessee has about 1.6 million liters of legacy waste containing 47,000 Ci of radioactivity in 40 tanks. (Though not HLW, this is included in the HLW section because the waste and tank problems are similar to those faced by HLW sites.) ORR also annually adds approximately 56,000 liters of active waste containing 13,000 Ci of radioactivity to 13 of their tanks.

- West Valley Demonstration Project (WVDP) in New York State has retrieved and vitrified approximately 95% of the 2.3 million liters of waste that was stored in 3 tanks.

To protect the public and the environment, this waste must be retrieved from the tanks and converted into an appropriate form for long-term disposal. DOE has signed Federal Facility Agreements (FFAs) with state and federal regulators that drive the scope and schedule for cleanup and closure of the tanks. The total life-cycle cost projected for HLW cleanup is $54 billion, as illustrated in Figure 3-1.

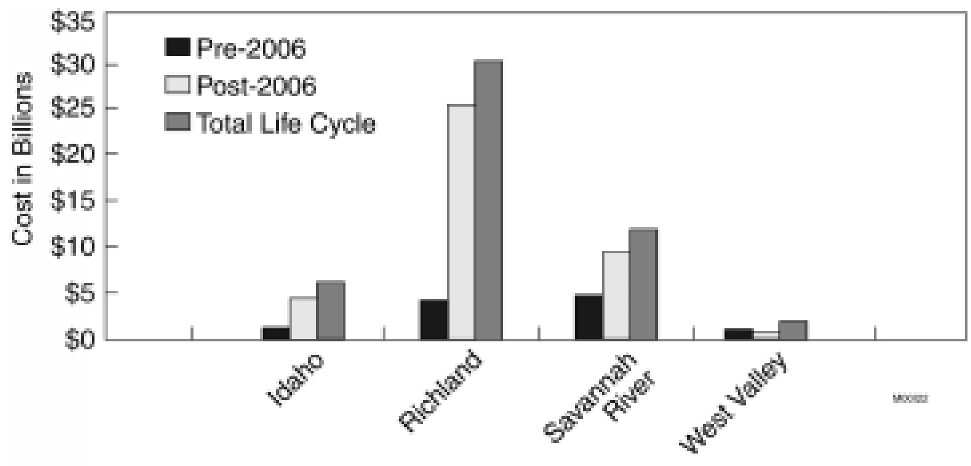


Figure 3-1. Through 2006, Post-2006, and Life Cycle costs for managing high-level waste.

National Context/Drivers and Federal Role

The Department continues to face a major radioactive tank waste remediation problem with over 300 underground storage tanks that have been used to process and store more than 90 million gallons of radioactive HLW and chemical mixed waste. Approximately 80 tanks are known or assumed to have leaked. Some of the tank contents have reacted to form flammable gases, introducing additional safety risks. These tanks must be maintained in a safe condition and eventually remediated and the waste disposed to minimize the risk of waste migration and/or exposure to workers, the public, and the environment. Many of the wastes within the tanks are unique, possessing characteristics that have never been encountered in the management of other industrial/radioactive wastes. These difficulties are compounded by the fact that programmatic drivers are more ambitious than baseline technologies and budgets will support. As a result science and technology investments are required to reduce the technical and programmatic risks associated with the tank remediation baselines.

HLW management is a problem unique to government. While some problems are shared with industries such as mining, oil production, and chemical, the hazards of working in a highly-radioactive environment with many materials of varying or unknown chemical and physical properties is truly unique. As other governments face similar issues, DOE actively engages other countries, notably Russia and the United Kingdom, to bring added expertise and technologies successfully used in those countries.

Generally, government-owned national laboratories perform HLW management research and development, with assistance from selected universities and private and foreign organizations. The Department is attempting to increase its use of existing private technology in the application of solutions to national HLW remediation problems at several sites. However, access to HLW is often not available to private organizations and research facilities unique to the government are required to handle these wastes. Local and national regulations also limit the transportation of HLW required for increased private sector involvement.

Linkage to DOE Strategic Goals and Objectives

The overall goals of the HLW management activities are to retrieve, treat, store, and dispose of HLW in a manner that is safe to humans and the environment, cost effective, and in compliance with all applicable environmental regulations.

The main goal for the HLW R&D investments is to systematically deliver and facilitate deployment of the necessary science and technology using an integrated approach to safely and efficiently achieve tank waste remediation across the DOE complex in support of the baseline cleanup plan. This goal supports the achievement of Environmental Quality Objectives EQ1, EQ3, and EQ6. By making the HLW in the tanks disposal ready, these investments also support Objective EQ5, complementing investments related to HLW disposal described in Chapter 7. The level of impact and support of the HLW science and technology investments on the Environmental Quality strategic objectives are shown in Figure 3-2.

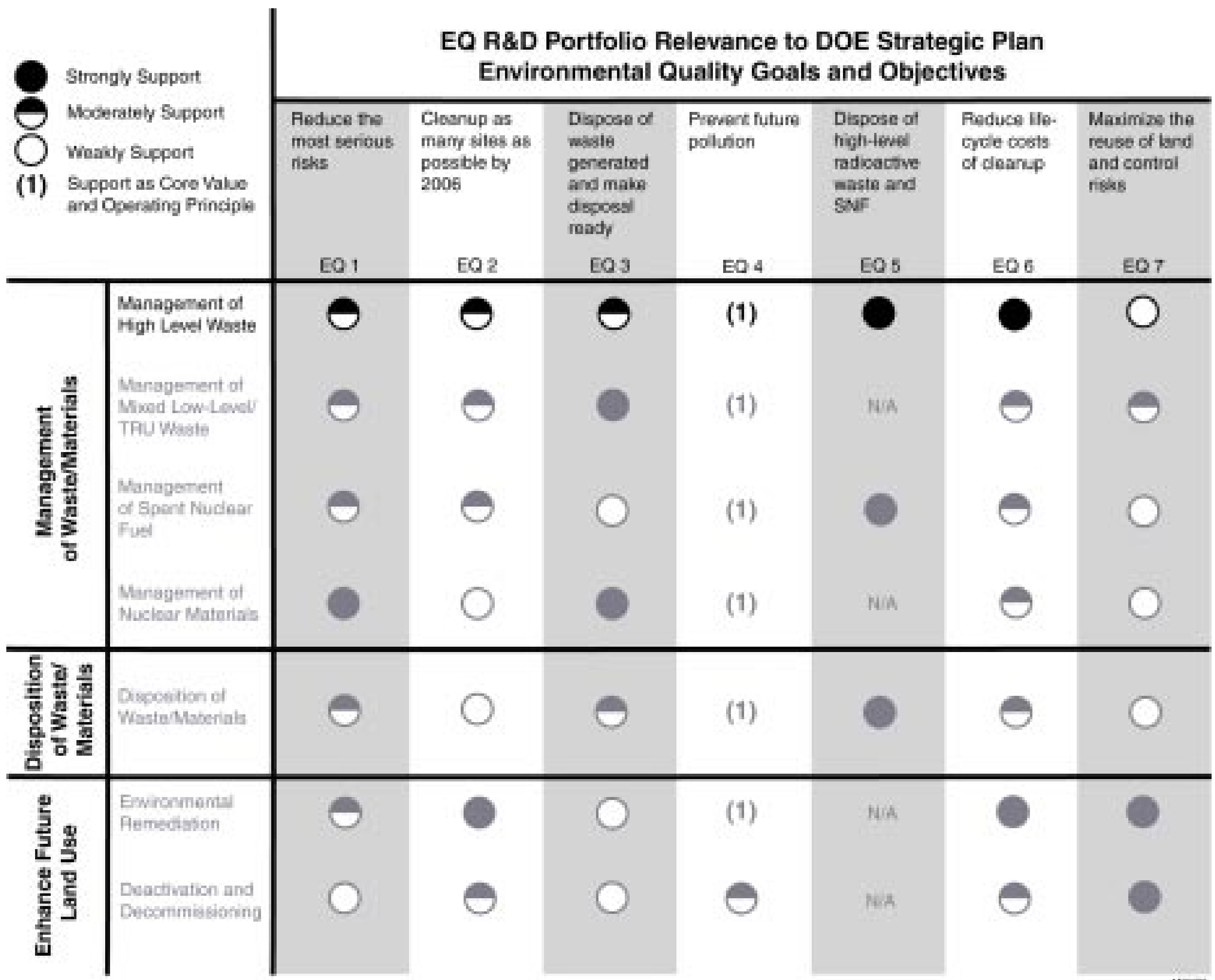


Figure 3-2. Relevance of high-level waste R&D investments to Environmental Quality goals and objectives.

Execution of the HLW R&D program will support complex-wide tank farm closure while minimizing life-cycle costs. Specific approaches include:

Approach #1: Increase use of DOE-funded results so that 70-90% of products are being used. The key point is the goal to *increase* the use of DOE-funded technologies. The following strategies assist in attaining this goal:

- Deliver technology as defined on schedule.
- Construct and maintain a leveraged program.
- Emphasize user/producer/developer teams.
- Understand functions, requirements, and schedule.
- Bridge the gap from fundamental science to technology implementation.
- Identify and build user relationships.

Approach #2: Reduce programmatic and technical risk. Essential elements of this goal are the constant pursuit of multi-site technology applications focused on the highest-priority, high risk needs of the users; and the selection of the best technical performers available to most effectively address technical risk issues. The following strategies assist in attaining this goal:

- Maximize multi-site benefits from technology investments and focus on activities with the greatest technical impact.
- Develop lab/industry partnerships that best respond to needs, ensure scientific and technical excellence, and deploy solutions.
- Manage and direct available technical resources in recognition of changes in site priorities and budget availability.

Approach #3: Direct up to 20% of the HLW problem area to contingency or alternative technology approaches. DOE will leverage technical expertise to anticipate problems and risk-reducing technical solutions. With the widespread support from its user community, the DOE pursues, within available funding, contingency or alternative technology approaches. The following strategies assist in attaining this goal:

- Continue to define strategic goals to guide technology investments.
- Continue to develop a basis for initiating and maintaining a forward thinking program that balances near- and long-term investments.
- Establish end-user advocacy for strategic investments.

Problem Area Uncertainties

The radiation levels associated with HLW pose extremely high worker health, safety and risk issues, requiring remote operation and maintenance of tank farm equipment and processing facilities, and storage and disposal of waste in underground facilities. Safety is the number one priority in the HLW program.

The chemical profile in HLW encompasses an extremely broad range of chemical constituents including nitrate and nitrite salts (approximately half of the total waste), hydrated metal oxides, organic complexants, phosphate precipitates, and ferrocyanides. This complexity makes the waste difficult to characterize, retrieve, process, and immobilize. In addition, the pH of HLW ranges from extremely acidic to extremely caustic. These factors, when coupled with the potential for radiolytic transformations, produce a problem that has no counterparts outside of DOE and for which there is a very limited knowledge base.

Other uncertainties adversely affect this problem area. The high costs associated with HLW management make it a frequent target for funding reductions and constant review. Because of these high costs, funding directed to technology development for this problem area has historically been insufficient to cover the technology needs expressed by the five sites. This has forced a program strategy that first responds to similar needs at several sites. Problems unique to one site have generally not enjoyed a priority high enough to receive available funding. For example, INEEL has highly acidic waste, which is unique. This has resulted in needs important to INEEL being unresolved.

Funding shortfalls also greatly restrict the ability to fund tasks that are more strategic in nature. Available funding has not been sufficient to respond to all the priority technology development needs, which are more immediate in nature, across the five sites. Beyond those immediate needs exists more general, investigative work that does not qualify as directed science. Solutions to these strategic needs also remain unresolved.

- Certain aspects of HLW management lengthen the time needed to deploy technical solutions. For example, key parameters such as agreements on a site’s end state and the identification of required cleanup levels must be negotiated with appropriate regulators and stakeholders at each site. These issues may be very complex; they often require considerable time for resolution.

- The complexity of HLW management problems amplifies the uncertainty inherent in research and development activities can lead to failures or setbacks. In-tank Precipitation was thought to be a viable waste treatment option at SRS. After considerable effort, it became apparent another alternative was required. However, without this considerable scientific and engineering effort, the true viability of In-tank Precipitation could not have been determined.

R&D Investment Trends and Rationale

To address the HLW problem, DOE investments span the full range of technical endeavor, from basic to applied research through technology development, deployment, and technical assistance.

Basic research answers fundamental questions of waste behavior (both in-tank and in the environment), while technologies developed through investments in applied research, technology development, deployment, and technical assistance are currently being used to satisfy nearer-term needs in waste characterization, retrieval, treatment, and immobilization, safe waste storage, and tank closure. Current and planned HLW investments are shown in Figure 3-3.

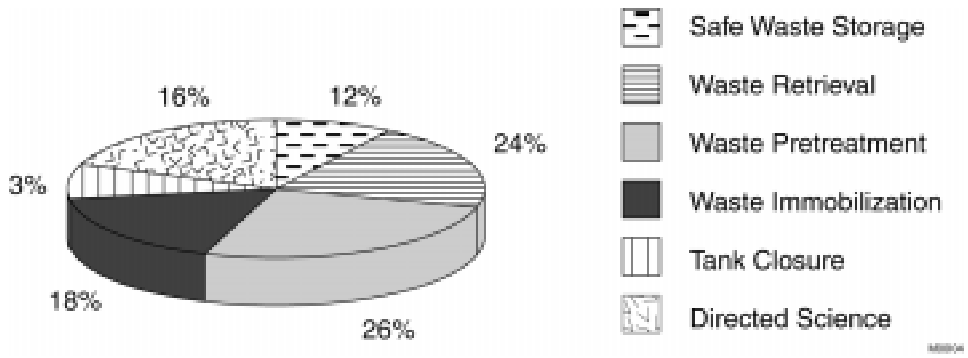


Figure 3-3. Cumulative investment in high-level waste areas over 3 years (FY 1999–FY 2001).

HLW research and development efforts fall into the following five major areas:

Safe Waste Storage. DOE's aging HLW tanks must be monitored to assure continued safe waste storage. The tanks vary in age, composition, size, shape, construction, and the environment in which they are located. The wastes inside these tanks also vary widely, creating additional challenges to maintenance of safe storage. Significant issues include tank integrity and corrosion, tank ventilation, and flammable gas generation.

Waste Retrieval. Tanks contain wastes ranging in consistency from soft sludges to concrete-like saltcake. Tanks also contain miscellaneous foreign objects, such as measuring tapes and in-tank hardware such as piping. Mixer pumps, retrieval pumps, and sluicing, adding large quantities of water to suspend solids, are the baseline methods for sludge removal from tanks, but these processes are not capable of retrieving all of the material from tanks. In addition, these methods may be problematic for some wastes and tanks. For example, sluicing has been questioned by stakeholders due to the existing and potential leaks of hazardous and radioactive liquids from corroded and deteriorated tanks into nearby soil and groundwater. Besides dealing with aging tanks and difficult wastes, retrieval also faces the problem of the tank design itself. Retrieval tools must be able to enter the tanks, which are under an average of 10 feet of soil, through small openings called risers in the tops of the tanks.

Waste Pretreatment. Although the total volume of waste is considered HLW, it is neither cost-effective nor practical to treat and dispose of all the waste to meet the requirements of the Nuclear Waste Policy Act. Large volumes of HLW will be generated while there is limited space for disposal. Only a small fraction of the waste is made up of radionuclides; the bulk of it is inert. Separation or pretreatment of the chemicals and radionuclides into high-activity and low-activity waste fractions will make for easier and more cost-effective treatment and disposal. Advancements in radionuclide separations, sludge processing, and solid-liquid separations science and technology are required to effectively pretreat DOE's wastes.

Waste Immobilization. Immobilization investments target solutions to problems in low-level, high-level, and secondary waste disposition. Unresolved technical issues in the development, implementation, and efficiency of grout, glass, and alternative-waste forms and processes exist. Other DOE investments address the government's interface with present and future privatized waste immobilization operations in such areas as waste form product acceptance testing and long-term immobilized waste form performance for disposal.

Tank Closure. Tank closure activities include the determination of closure criteria; stabilization of waste tanks for closure; the characterization, retrieval, and treatment of remaining waste residues in the form of tank heels and contaminated ancillary equipment; and the continued monitoring of waste tank sites after closure. DOE invests in research and development in all of these areas.

Key R&D Accomplishments

Deployment of solutions to address site needs is the critical measure of success for DOE investments to solve HLW problems. The nature of those problems and the technical solutions and schedules vary according to the nature of the specific needs and performance objectives defined by site problem owners. Accomplishments vary from delivery of critical technology evaluation information or process data to deployment of treatment processes or systems in remediation operations. Deployment of data is accomplished when data are used by site problem owners to support: 1) key HLW storage, treatment and disposal decisions involving improvements to existing processes, 2) selection of future technologies and processes, and 3) evaluation of comparative costs and technical viability of options.

In order to monitor progress towards technical objectives and increase probability of success, key deliverables are identified that represent significant progress, accomplishments, or interim steps towards delivery of technical solutions. Progress toward delivery of solutions is measured in three areas:

- Delivery of data to support key decisions and fill gaps in technical knowledge required to define the path to solution.
- Demonstration of technologies or concepts to support selection of technology alternatives or demonstrate progress towards deployment of selected technologies.
- Deployment of technical solutions, including implementation of data in a baseline program and actual installation and operation of technologies in a tank, tank complex, or waste treatment facility.

To date, key accomplishments addressing HLW management needs include:

- Grouted and closed two HLW tanks.
- Retrieved residual waste from seven tanks using remotely operated deployment systems and innovative waste dislodging and conveyance tools.

- Deployed system to remove and isolate in-tank piping to prepare for tank closure.
- Adapted and deployed power fluidic technologies proven in the United Kingdom to sample wastes from one tank and retrieve waste from five tanks.
- Deployed auger for sampling and magnetometer for measuring waste volume to improve residual waste inventory estimates for performance assessment.
- Provided critical technical expertise, technology options, and performance data to assist in selecting alternatives to replace the in-tank precipitation process; two options were selected for further testing, demonstration, and ultimate downselection.
- Adapted and deployed mining industry technologies to retrieve waste from five limited access waste tanks.
- Conducted hot-cell analysis of tank waste using advanced spectroscopy technologies.
- Deployed pulsed-air and in-line slurry monitoring technology to selectively mobilize and monitor solids for pipeline transfers between tank facilities.
- Deployed in-tank corrosion monitoring technology to limit sodium inhibitor additions, ultimately reducing waste volume for disposal.
- Deployed laser-based mapping technology to investigate condition of concrete tank walls.
- Deployed ion-exchange, mobile evaporator, and solid-liquid separations technologies to process liquid waste reducing cesium content, volume, and solids contents, freeing up limited tank waste storage space.
- Delivered critical data for vitrification process control enabling increased waste loading at the Defense Waste Processing Facility (DWPF).
- Continued LDUA deployment at INEEL to sample tank residuals, evaluate tank integrity, and support strategy development for accelerated tank closure.
- Completed closure alternative recommendations for Hanford to support definition of a process for defining closure criteria.

Key R&D Issues

HLW management will require both near-term and long-term science and technology investments to ensure safety, reduce technical and programmatic risks, reduce costs, and enable processing and treatment to be accomplished over the next half century. Near term issues, objectives, and current program description are described in later sections. Longer-term R&D issues for each of the major areas of HLW management are described below.

Safe Waste Storage. Many of the radioactive storage tanks are quickly approaching or have exceeded their design life. Although tank chemistry is controlled to prevent corrosion, stress corrosion cracking has occurred in several tanks and is likely to continue. HLW management will require more than 35 more years of waste storage in many of the aging tanks before all of the waste can be retrieved and processed. In addition, processing delays and secondary waste generation are likely to require even more interim waste storage until processing can be completed. Therefore, there will be an increasing need for monitoring, prevention, and repair to maintain tank integrity and allow use of existing tanks during the life of the HLW program. The most likely problems in Safe Waste Storage will arise from corrosion-induced failure of aging waste tanks requiring costly construction of new tanks or repairs to allow processing to proceed. Mechanisms of corrosion, improved monitoring and control, and methods to inspect for, detect, and mitigate tank defects will be required.

Waste Retrieval. Near-term issues are focused on bulk waste mixing and retrieval to support feed delivery for processing. In addition, several sites have accelerated tank closure efforts and therefore require heel retrieval and tank cleaning technology. Longer-term issues will focus on heel retrieval from more complicated tanks, such as those with internal equipment, piping, etc. Waste from single-shell tanks with high risk of leakage will need to be retrieved with minimal water addition. To remediate tanks within the established schedule, the outyear baseline assumes that retrieval operations can be performed from multiple tanks simultaneously to achieve feed delivery and processing rates. However, the more difficult tanks and waste types are likely to be encountered in the outyears. Likely long-term problems will include failure of baseline technology to retrieve adequate volumes of tank waste to meet regulatory requirements, tank integrity failure due to aggressive retrieval operations, and inadequate retrieval capacity to maintain feed to processing facilities. Science and technology will be required to:

- Enable dry or reduced-water retrieval to avoid leakage to the vadose zone
- Improve heel retrieval technology with significantly reduced costs and higher rates of mobilization to meet baseline schedule and cost assumptions
- Build a solid understanding of tank waste chemistry to avoid unwanted upsets in retrieval and transfer due to plugged lines and other waste behavior issues.

Waste Pretreatment. Although solid-liquid-separation, supernate processing, and sludge processing technologies exist today that can meet near-term baseline schedules, pretreatment represents a significant portion of the HLW management costs, and a significant technical risk. Outyear processing will likely involve the more complex wastes. Secondary waste generation and waste recycle streams also contribute greatly to the volume of waste ultimately requiring treatment. Likely failures in pretreatment will involve inadequate separations due to changing waste feed chemistry, and a subsequent increase in costs of downstream waste immobilization and disposal. Advancements in separations technology will need to continue to be made to provide lower cost, more efficient alternatives that can greatly improve this portion of the tank remediation flowsheet. Reductions in the volume of waste requiring disposal as an immobilized low-activity or high-activity waste form will greatly reduce costs.

Waste Immobilization. Baseline immobilization processes have or are being established for each of the HLW sites. However, immobilization processing conducted to date at several sites confirms the need for longer term R&D to greatly improve operations, reduce costs, and increase throughput to allow baseline schedule and cost assumptions to be met. For example, design problems with the SRS melter pour spout has decreased throughput and increased costs of operations. New melter designs are needed to correct this problem. Future efforts will be needed to improve performance and reduce the total number of canisters to be produced.. Likely problems in immobilization will arise from feed delivery or pretreatment limitations that decrease the efficiencies of immobilization processing, reduce waste loadings, and increase the number of waste form canisters produced—increasing costs. In addition, glass melter failures will occur as more waste is processed and more systems come on line across the DOE complex. Failures will demand melter design improvements to mitigate future problems. Science and technology investments will be required to improve waste loadings, increase waste form disposal performance, and increase process throughput to meet schedule and cost baselines.

Tank Closure. Uncertainties in “how clean is clean”, reliability of predictions of long-term contaminant migration and public exposure, and limitations in retrieval technology performance will drive the long-term issues in Tank Closure. As waste retrieval and processing proceeds, more and more sites will pursue tank closure to reduce mortgages. However, uncertainties in performance assessment models and transport data at some sites will make it difficult to establish acceptable closure criteria. Retrieval of tank waste heels or residuals will become difficult as more complex tanks undergo waste removal. Stabilization of waste residuals may need to consider means of incorporating higher volumes of waste while maintaining acceptable protection of the vadose zone, groundwater, and public.

Problem Area R&D Program

Budget: FY99-54.8M, FY00-$59.5M, FY01-$62.0M

Program Description

The key problems faced by DOE sites, as indicated by their nearer-term submitted needs and longer-term program baseline summaries, fall into five technical areas reflecting the steps in HLW management: safe waste storage, waste retrieval, waste pretreatment, waste immobilization, tank closure, and the characterization and monitoring required for each of these process steps. Disposal of low-activity waste forms is also included in the immobilization area. The nearer-term investment strategy in each of these technical areas is described below. Longer-term research issues and objectives were described previously. Characterization and monitoring is discussed in the context of the other technical areas it supports.

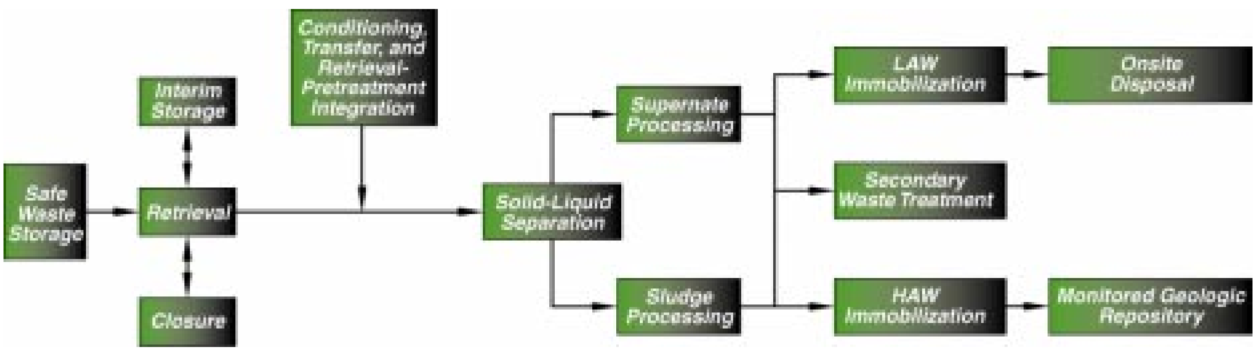


Figure 3-4. Generic tank remediation flow sheet.

Figure 3-4 shows the HLW remediation process. HLW will be retrieved from the tanks and processed (or pretreated) to separate it into a smaller amount of high-activity waste (which is costly to dispose) and a large fraction consisting of common chemicals contaminated with low levels of radioactivity. Both fractions will then be immobilized, creating durable solid wastes. The high-activity waste (HAW) will be shipped to the Federal geologic repository, while the low-activity waste (LAW) will be disposed onsite. The nearly empty tanks will be closed in accordance with regulatory agreements that are not yet established in most cases. HLW cleanup will take many years to complete; current project plans predict that all waste will be treated and tanks closed by 2046. In many cases, institutional management measures, such as land use restrictions and groundwater monitoring, will be applied following tank closure. DOE will make continued progress in waste tank closure, answer key technical questions, and develop more cost-effective alternatives by accomplishing the following near-term goals:

- Provide heel retrieval and characterization systems or technologies necessary to support the closure of 16 radioactive waste storage tanks by 2006. Efforts will demonstrate progress toward, and technology capability needed for post-2006 retrieval closure of the majority of remaining radioactive storage tanks. Near-term efforts will include two tanks each at Hanford, INEEL, ORR, WVDP, and SRS.

- Support tank farm closure activities by developing and deploying screening and sampling tools for residual tank waste and leaked waste inventory assessments.

Efforts will support the near-term schedules for tank closure, and establish the technical basis and benchmark process for full tank farm closure post-2006.

- Provide data deliverables, performance specifications, and hardware supporting deployment of improved waste mixing and retrieval systems for double- and single-shell tanks by 2001 to support waste feed delivery to processing facilities. Efforts will establish the basis for planning more aggressive waste retrieval efforts to support full-capacity processing post-2006.

- Develop data and technologies to further DOE's ability to oversee and monitor privatization of designated tank waste remediation functions.

- Develop and deploy by 2001 sensors to monitor 1) tank corrosion and support tank life extension requirements, 2) waste processing, 3) waste transfer and retrieval, and 4) waste and immobilized waste storage. Near-term efforts will reduce mortgages and risks of waste storage and processing. Longer-term efforts will be required to ensure tank integrity many years past the design life of current systems.

- Develop and deploy technologies to reduce the volumes, including water-balancing techniques, of both high-activity and low-activity tank wastes.

- Improve waste loading for high-level vitrified waste at SRS by 2001 and better understand melter glass chemistry to support long-term improvements in high-activity waste processing.

- Develop a technical basis for immobilized waste product performance at INEEL and Hanford by 2001 to support design efforts and early privatization efforts.

- Develop and demonstrate lower cost solutions to support waste processing needs, such as low-cost mixers, thereby reducing long-term mortgages.

- Identify issues and develop solutions to waste remediation technical gaps that may exist between the interfaces of retrieval, pretreatment, immobilization processes, and the closure function and final waste state.

Safe Waste Storage

Budget: FY99-$6.0M, FY00-$6.2M, FY01-$8.9M

Objectives and Activities. Investments in safe waste storage are needed to fill technical gaps, reduce costs, and avoid costly problems while ensuring protection of the public and environment. Priority site needs are focused on science and technology to: 1) improve tank integrity monitoring and corrosion prevention to extend tank life, 2) improve tank ventilation to reduce costs, 3) improve waste characterization to support retrieval, and 4) reduce through source and recycle stream waste reduction the volume of waste entering the tank farm.

Extending Tank Life—The near-term goal to avoid tank corrosion is to improve upon methods for maintaining tank waste chemistry within site specifications by adapting commercial monitors for in-tank analysis of inhibitors and major species that control corrosion rate. The longer-term strategy for avoiding corrosion in tanks includes development and assessment of corrosion monitoring methods that provide more direct and real-time measurement of the corrosion potential within a tank than do corrosion coupons. The strategy for evaluating tank integrity also includes near- and longer-term approaches. Commercial non-destructive examination (NDE) techniques will be deployed near-term using an arm-based or crawler-based system to inspect tank walls. Longer-term efforts will integrate needs from multiple sites to define, develop, and test the specific systems needed to inspect tank floors, inspect surfaces below a liquid level, and assess a tank's integrity before reuse or waste retrieval. Specific support provided by DOE to replace the baseline techniques include:

- Developing an electrochemical noise corrosion monitor, which is deployed through a tank riser, for use at SRS and Hanford, and ORR.

- Deploying a Raman-based nitrate, nitrite, and hydroxide (NO_2^-/NO_3^-/OH^-) in-tank sensor for corrosion inhibitor concentration monitoring at SRS.

- Deploying NDE end effectors with a Light-Duty Utility Arm (LDUA) or crawler-based platform.

- Ventilating Tanks—DOE's goal is to reduce the cost of active ventilation of HLW tanks. Specific activities include selecting and demonstrating regenerable filter systems to replace high-efficiency particulate air (HEPA) filters within the existing active ventilation system. A commercial system will be procured for demonstration and deployment.

Characterize Waste—DOE's goal is to invest in tools and methods to: a) monitor corrosion and leak detection for safe waste storage; b) monitor process control for feed staging, slurry transfers, sludge washing, LLW and HLW immobilization; c) assess residual waste inventory for tank closure; and d) post closure monitoring of tanks and waste storage facilities. Specifically, DOE's activities will:

- Deliver and deploy slurry monitoring systems to support waste transfers and reduce the risks of pipeline plugging.

- Deploy fluidic sampler and at-tank analysis system into Hanford waste tank to support feed staging for waste treatment.

Reduce Waste Volumes—DOE's goal is to implement technologies to reduce source and recycle streams at SRS and INEEL. Specifically, DOE will:

- Deploy evaporator technology for SRS Consolidated Incinerator Facility.

- Deploy waste volume minimization technologies at INEEL.

- Demonstrate mercury removal on INEEL wastes.

Accomplishments:

- Processed 22,000 gallons of liquid waste from ORR Melton Valley Storage Tanks (MVST) through the mobile, out-of-tank evaporator system freeing up additional tank waste storage space.
- Deployed LDUA in INEEL tanks for sampling and NDE inspection to support development of closure planning to meet agreements with the State of Idaho.
- Lessons learned from hot demonstration of first- and second-generation electrochemical noise (EN) corrosion probes being incorporated into probes for deployment at Hanford and SRS; new generation probe deployments planned 2000 at Hanford and SRS.
- Demonstrated Raman spectroscopy technology on SRS tank waste samples. Developed integrated corrosion probe design including both Raman and EN corrosion monitoring capabilities for SRS tanks.
- Deployed laser-based Topographical Mapping System technology in the ORR Gunite tanks to measure the extent of concrete spalling of tank walls.
- Issued industry call for regenerable HEPA filter technology for SRS; selected two vendors and completed initial testing and demonstration activities.
- Deployed fluidic sampler for SRS tanks and demonstrated multiple-depth concept for Hanford tanks.
- Deployed Laser Ablation Mass Spectrometer for tank waste compositional analysis and Near Infrared Spectrometry for moisture content analysis in Hanford analytical hot cells.

Waste Retrieval

Budget: FY99-$12.7M, FY00-$11.3M, FY01-$18.6M

Objectives and Activities. Investments in waste mobilization and retrieval fill technical gaps and reduce costs while ensuring safe operations. Near-term waste retrieval investments focus on bulk waste mixing and retrieval to support feed delivery for processing. Longer-term problems, beyond 2006, involve retrieval from more complicated tanks, those with internal piping or equipment, single-shell tanks with higher leakage rates, and more difficult waste types. Alternatives must be in place for the long-term in the event baseline technologies cannot retrieve adequate volumes of tank wastes to meet regulatory requirements, and in the event aggressive retrieval operations risk tank integrity, or retrieval capacities do not meet processing facilities' optimum feed rates.

Mobilize Bulk and Heel Waste—Mobilizing bulk and heel wastes within a tank is required to remove materials for tank closure, treatment, and ultimate immobilization and disposal of the hazardous waste components. Mobilizing dense sludge, saltcake, and dry/hardened materials is particularly challenging and important for retrieval operations. Baseline methods for waste mobilization are mixer pumps and long-range, high water volume sluicing. The goals are to provide the following technologies and technical solutions to support priority retrieval needs at SRS, ORR, Hanford, and West Valley. Specific activities will:

- Provide technical solutions to mix, mobilize, and transfer wastes from 26 tanks at ORR.
- Demonstrate commercial technologies for retrieving calcines from INEEL storage bins.
- Deliver and deploy Russian Pulsating Mixer Pump in ORR GAAT tanks.
- Demonstrate and deploy retrieval technologies for small, horizontal tanks with limited access.
- Deploy a sludge retrieval system at SRS.
- Deploy heel retrieval equipment for SRS Type I, II, and III tanks.
- Develop and test tank heel retrieval technologies for obstructed tanks at West Valley.
- Demonstrate alternate mixing technologies for Hanford and SRS.
- Recommend improvements to existing mixer pumps at Hanford and SRS.
- Deploy chemical tank cleaning at SRS.
- Deploy sampling and retrieval systems for 1F Evaporator at SRS.

Detect and Mitigate Leaks—The goals are to provide retrieval methods that avoid leakage by controlling and minimizing water, provide leak detection devices that can rapidly output data to guide retrieval operations, and create strategies to mitigate leaks once detected during retrieval. To address this goal, activities will:

- Emphasize industry support and technology to develop methods for leak detection and mitigation.

Transfer Waste—The goals are to deliver data and systems to reduce the risk during waste retrieval and waste transfers. Retrieved wastes need to be transferred, and may require monitoring and conditioning to avoid problems with re-precipitation, solids formation, plugging of transfer lines, and settling or simply to enhance downstream processing. Investments are needed for data and technologies to ensure the interface between retrieval and pretreatment avoids unwanted problems. Specific activities will:

- Evaluate the impacts of physical and chemical conditions on waste rheology and transfer for Hanford, ORR, and SRS waste types.

- Identify and test pipeline plug-locating technologies.
- Adapt and test commercial systems for pipeline unplugging with side-by-side testing to evaluate the merits of a variety of systems. Functions and requirements, primarily from Hanford and SRS, will be used to select and test industry technologies acquired through a joint program between DOE and private industry.

Monitor and Control Retrieval Process—The goals are to support retrieval and transfer operations with appropriate monitoring systems to avoid process upsets. Specific activities include the deployment of on-line slurry monitoring to support GAAT retrieval at ORR.

Accomplishments:

- Completed testing and demonstration of Russian-designed pulsating monitor technology for use in tank mixing and retrieval; initiated procurement of system for deployment in ORR tank.
- Retrieved six GAAT tanks using Modified Light-Duty Utility Arm (MLDUA), Houdini, and Confined Sluicing technologies; work continuing on seventh tank with goal of retrieving eight GAAT tanks.
- Deployed pipe cutting and capping technologies deployed by MLDUA to cut and isolate internal piping in GAAT tanks to remove obstructions and prevent in-leakage of additional water after completion of tank retrieval.
- Deployed Pulse Jet Mixers in ORR BVEST successfully removing 32,000 gallons of sludge waste from five tanks.
- Demonstrated extendible nozzle borehole miner technologies used in mining industry for retrieval of small, horizontal tanks and deployed Borehole Miner system in five ORR Old Hydrofracture Tanks successfully removing all remaining sludges required to prepare the tanks for closure.
- Deployed PulsAir™ mixing technology at GAAT Tank W-9 selectively mobilize settled solids for transfer of waste to MVST facility.
- Completed sensor testing and integration in-line solids monitoring technology to support pipeline transfer of waste from GAAT Tank W-9 to MVST facility.
- Completed SRS Tank 16 annulus sampling, lab analysis and performance assessment modeling.
- Completed sluicing nozzle testing and provided recommendations for sluicing operations at Hanford Tank C-106.
- Conceptual designs and tank interface requirements delivered by two vendors for Hanford Tank C-106 heel retrieval; selected preferred vendor/technology.

- Conducted technology exchanges with Russian tank waste experts to promote sharing technical knowledge of retrieval experience and transfer technologies.

- Deployed fluidic mixing system in SRS pump tanks to mix settled sludge materials to improve waste removal operations. Demonstrated design enhancement to include mixing floating organic layers along with sludge mixing capability.

Waste Pretreatment

Budget: FY99-$12.7M, FY00-$16.1M, FY01-$17.2M

Objectives and Activities. Investments in waste pretreatment must be fully integrated with waste immobilization, which receives feed from pretreatment processes, and waste retrieval, which provides feed to pretreatment. The pretreatment step is critical to reducing the volume of LLW and HLW products; this reduces disposal costs. Investments include: 1) preparing retrieved waste for transfer and pretreatment, 2) clarifying liquid streams through solid-liquid separations, 3) supernate processing to remove radionuclides, and 4) sludge processing to remove excess chemical species that either increase the volume of HLW or adversely impact the performance of the HLW form. In addition, pretreatment addresses Interim Storage issues associated with INEEL's calcination and subsequent calcine dissolution.

Pretreatment requirements beyond the year 2006 will likely consider more complex wastes, and will continue to address secondary waste generation and waste recycle streams. Advancements in separations technology will be needed to provide lower cost, more efficient alternatives to present methods. Waste volume reduction techniques directly impact the eventual cost of waste immobilization, and investments to reduce waste volumes are required.

Prepare Retrieved Waste for Transfer and Pretreatment—The goal is to ensure retrieved wastes are ready for downstream processing. Specific activities will:

- Evaluate saltcake dissolution and concentrate re-precipitation phenomena in complex solutions using nonradioactive surrogates to upgrade thermodynamic models and support retrieval and storage operations at Hanford for privatization.

- Demonstrate chemical pipeline unplugging methods resulting from the study of the phenomena of pipeline plugging and scale buildup associated with waste retrieval, transfer, and treatment of SRS and Hanford wastes.

Clarify Liquid Streams—The goal is to deliver data and technologies to meet ORR, SRS, Hanford, and INEEL needs for process selection. Specific activities will:

- Deploy cross-flow filtration system for treatment of MVST supernate.

Remove Radionuclides—This includes reducing the levels of cesium, technetium, strontium, or TRU to meet LLW disposal requirements onsite. The goal regarding radionuclide removal for alkaline wastes is to deliver improved cesium separations systems to reduce cost and technical risk at ORR and SRS. Specific activities include:

- Evaluate crystalline silicotitanate (CST) and other sorbents (such as monosodium titanate) or extraction processes to develop and deliver an alternative processing system for salt disposition at SRS.

- Deploy process monitor to detect and measure cesium in process effluents.

The goal for transuranic (TRU), cesium, and strontium removal from acidic wastes is to provide performance and engineering data to INEEL users on solvent-extraction and ion-exchange processes to confirm their baseline process assumptions, support the record of decision, and support Title 1 design. Specific activities will:

- Demonstrate TRU and strontium solvent-extraction processes at the INEEL with actual liquid wastes and dissolved calcine.

- Develop an integrated cesium solvent-extraction process for consideration as part of the INEEL flowsheet.

- Test alternative cesium and strontium separation processes to provide additional performance data to support flowsheet development and downselects.

Process Sludge—The goal is to provide Hanford with baseline processing data to support phase II privatization. Specific activities will:

- Evaluate chromium removal performance during sludge washing and identify methods (e.g., oxidative leaching and caustic leaching) to improve chromium removal to ensure a baseline exists that can reduce the impact of chromium on HLW glass volume and subsequent immobilization costs.

Interim Storage—The goals are to provide data and technology to enable waste processing at INEEL. Specific activities include the evaluation of the chemistry and dissolution behavior of existing calcine and bench-testing of preferred dissolution schemes to support flowsheet design decisions.

Accomplishments:

- Processed over 30,000 gallons of ORR MVST waste effectively removing 1,142 curies of cesium-137 using CST ion exchange technology deployed in a modular CPU.

- Completed sludge washing studies using actual tank waste samples from Hanford tanks and completed analysis for leachate chemistry for removal of problem constituents (e.g. Chromium) to reduce waste volume and improve performance of immobilized waste product.

- Completed demonstration of cross-flow filtration (CFF) technology and deployed a CFF-based solid-liquid separation CPU for treatment of MVST waste.

- Completed dissolution studies on calcined waste and testing of the CFF-based Cells Unit Filter (CUF) technology for use in separating residual calcine solids from liquid waste to support development of a waste treatment flowsheet for Idaho.

- Tested analytical models for Hanford saltcake dissolution and applied technology to assist Hanford in evaluating options for mitigating saltcake crust growth issue in tank SY-101; performed confirmatory hot-cell analysis on actual tank waste samples.

- Provided preliminary data on recommended operating envelop for Hanford pipeline waste transfers.

- Completed cesium removal testing on actual tank waste samples from INEEL tanks to support waste treatment flowsheet development.

- Supported SRS HLW program by technical assistance and recommendation on technologies for replacement of the SRS in-tank precipitation process; participated in evaluation of alternatives and development of recommendations. Conducted lab-scale testing on the CST alternative providing data for down select of preferred technology.

Waste Immobilization

Budget: FY99-$11.2M, FY00-$10.4M, FY01-$10.1M

Objectives and Activities. Waste immobilization includes LAW immobilization, HAW immobilization, and disposal of LAW and HAW. The LAW streams produced during pretreatment separation operations at each of the tank waste sites will require immobilization to produce an acceptable waste form for disposal. Each of the DOE tank waste sites are considering different immobilization and disposal options for LAW, ranging from grout to glass, and from onsite to off-site disposal. SRS is operating their saltstone (grout) LAW immobilization process. Hanford has selected LAW vitrification through a privatization contract. DOE's science and technology activities are focused primarily on INEEL's LAW immobilization for which a final solution has not yet been determined, and support to Hanford's privatization and onsite disposal of final LAW forms. Needs exist for product acceptance testing to ensure the LAW immobilization process produces an acceptable waste form, data collection to support performance assessment efforts, and evaluation of disposal site barrier technologies to ensure the final disposal of the immobilized LAW meets requirements.

Immobilization of the HAW streams at the INEEL, SRS, and Hanford is required to produce an acceptable HAW form for final disposal. Vitrification is the baseline methods for HAW immobilization. In addition to the vitrification processes, melter feed preparation, process monitoring, and process control methods are required to produce acceptable waste forms.

The baseline technology for HAW processing is vitrification at all of the tank sites with this process being operational at SRS and West Valley. At SRS, methods that can reduce the cost of operation are being identified and evaluated. Cost reduction can occur through optimization of waste loading that reduces the number of glass canisters produced and improvements in process equipment and materials of construction that reduce maintenance and downtime by reducing corrosion or other material failure problems. At Hanford, optimized waste loading and melter selection are considerations for developing the baseline to support phase II privatization, especially with regard to concerns about high chromium wastes and their compatibility with current melter designs and waste formulations. At INEEL, waste formulation for sodium-bearing waste and calcined wastes followed by melter testing is needed to meet an accelerated schedule for the record of decision (ROD) and the FY00 Title 1 design schedule. Corrosion of melter materials from the acidic wastes at the INEEL is a key issue that must be addressed with both formulation and materials development and testing.

Efforts are focused on reducing cost and enhancing the baseline at SRS, as well as filling technical gaps in the baseline for Hanford and INEEL.

Process LAW—The goals are to establish baseline processes for INEEL and ORR LAW immobilization. Specific activities will:

- Evaluate sorbents and stabilizers to enhance performance of INEEL and ORR LAW.
- Demonstrate grouting of INEEL Newly-Generated Liquid Wastes.

Process HAW—The goals are to reduce costs of HAW processes at SRS and to reduce the technical risks of HAW processing at INEEL and Hanford through process definition. Specific activities will:

- Optimize waste loading for components such as iron, aluminum, silicon, zirconium, and alkali cations in SRS and Hanford wastes, and determine solubilities in glass of minor components such as chromium, phosphate, halides, technetium, and actinides to optimize waste loading of these components.
- Establish glass compositions for INEEL's sodium-bearing and calcined wastes to avoid highly corrosive environments and produce acceptable waste forms.
- Test innovative and next generation melters for use at INEEL to ensure compatibility of wastes and materials of construction.
- Develop and demonstrate equipment improvements such as melter pour spout, improved melter designs, and improved remote operations for DWPF to reduce downtime and increase throughput.
- Review potential alternatives to large-scale HLW melters, processing systems, and facilities.

Dispose of LAW—The goal is to ensure that data to support the design of LAW disposal systems are available. Specific activities will:

- Provide technical data relating glass composition and waste form durability to support product acceptance and performance assessment analyses.

Accomplishments:

- Demonstrated stirred-melter and researched improved melter designs for second generation DWPF melter and INEEL melter selection. Demonstrated melter pour spout and knife-edge design improvements for DWPF operations.

- Delivered liquidus temperature data and recommendations for process control improvements to be implemented in the DWPF process control system to increase waste loading in glass canisters.

- Completed thermal denitrification and melter material testing and initiated glass formulation investigations to support development of INEEL waste immobilization flowsheet.

- Delivered data on grout versus glass performance and cost to support ORR in evaluating immobilization options for MVST waste.

- Transferred experience and technology from the United Kingdom to demonstrate grout technology for sodium-bearing and newly generated liquid waste at INEEL.

- Provided technical assistance to Hanford in evaluating data and risks for privatization of tank waste vitrification.

Tank Closure

Budget: FY99-$2.7M, FY00-$1.0M, FY01-$2.0M

Objectives and Activities. Closure of radioactive waste tanks requires sampling and/or characterization of waste tank residuals, definition of and compliance with closure criteria (i.e., "how clean is clean?"), and stabilization of the tank "potentially including barrier technology." Stabilization of the tanks and installation of surface or subsurface barriers may be required following retrieval and post-retrieval characterization, to prevent subsidence of a tank, collapse of the domed top, long-term migration of residual contaminants, or short-term release of residual waste contents due to catastrophic failure. Stabilization may encompass filling the tank with grout and stabilizing wastes, or a simple gravel fill to prevent tank dome collapse. Barrier technology may include engineered surface barriers to prevent water, plant, and animal intrusion, or subsurface barriers that prevent contaminants or moisture from migrating downward to the water table.

Closure of radioactive waste tanks has become a key element in the tank sites' baseline plans for reducing mortgage and accelerating cleanup. SRS has closed two HLW tanks and is planning its closure of OBG Tanks. ORR is preparing for future GAAT tank closures and will be closing its OHF tanks. INEEL is planning two tank closures for FY03. Investments in tank closure include advancements in grout formulations and delivery methods to reduce costs and improve performance for immobilizing residual tank waste and stabilizing SRS and ORR tanks. In addition, all aspects of tank isolation and stabilization for ORR and establishment of a basis for closure at Hanford and INEEL are required to reduce mortgages and move forward with retrieval and final tank closure decisions. The goal is to deliver the technologies and data to enable all five tank sites to proceed toward closure. The following are specific activities relating to this goal.

- Continue LDUA deployment at INEEL to sample tank residuals, evaluate tank integrity, and support strategy development for accelerated tank closure.
- Develop and demonstrate grout formulations supporting INEEL's Tank WM-182 Closure Demonstration.
- Deploy characterization, retrieval, out-of-tank processing of retrieved waste, and process monitoring at ORR GAAT to prepare for closure of the North and South Tank Farms by 2002. DOE developed and deployed tools using the MLDUA to isolate and plug tank penetrations (e.g., piping).
- Grout and close smaller tanks at ORR and support decisions at SRS through testing and deployment of improved multipoint grout injection methods.
- Sample and retrieve wastes from ancillary equipment, such as a tank farm evaporator at SRS to support closure of the remaining tanks and tank farm at SRS.
- Investigate the impacts of technetium under waste removal and tank post-closure activities.
- Provide technical assistance to Hanford vadose zone planning and investigations.

Accomplishments:

- Completed grouting and isolation of SRS Tanks 17 and 20 to support closure; received approval of closure from South Carolina.
- Completed feasibility demonstration of the multi-point grout injection technology for ORR Old Hydrofracture Facility tanks.
- Completed closure alternative recommendations for Hanford to support definition of a process for defining closure criteria.
- Issued grout formulation and emplacement specification for stabilization of GAAT tanks prior to closure.
- Demonstrated Cone Penetrometer deployment platform, multi-sensor probe, and multiple soil sampler technologies for vadose zone deployment at Hanford.
- Delivered technical assistance to Hanford by participating in vadose zone/groundwater project panel meetings and advisory reviews.

Directed Science

Budget: FY99-$9.5M, FY00-$14.5M, FY01-$5.0M

Within the High-Level Waste investment portfolio, DOE funds research that advances science to solve environmental problems associated with storage tanks containing highly radioactive wastes. DOE provides funding to conduct basic research addressing fundamental issues that may be critical to achieving EM's mission and goals. Since 1996, EM has awarded a total of 69 projects addressing the high-level waste as the primary problem area. Of the 69 projects, 26 concluded at the end of FY99 and the results are being incorporated into TFA technical responses to site needs as appropriate. An additional 54 projects address other problem areas but may be applicable to HLW needs. DOE monitors the progress of those projects that are specifically applicable to site science needs and HLW technology needs including:

- Technetium chemistry
- Chemical and physical property measurement
- Radionuclide separations
- Waste chemistry and physical properties
- Tank corrosion
- Improving HLW glass waste forms
- Validating waste form performance
- Characterizing moisture and contaminant concentrations and transport in the vadose zone beneath tanks and disposal facilities.

Several new projects addressing subsurface contamination in the vadose zone were initiated in FY-1999 and are of particular interest to the Subsurface Contamination Focus Area (See Directed Science in Chapter 8). DOE will evaluate these most recent awards for potential application to tank closure waste disposal technology needs.

The most promising and applicable basic research projects will transition to applied research or more advanced stages of technology development. The present HLW directed research portfolio is concentrated in the scientific areas of actinide chemistry, analytical chemistry and instrumentation, engineering science, geochemistry, hydrogeology, inorganic chemistry of tank wastes, materials science, and separations chemistry. The following is a brief summary of research projects that are in progress in each of these scientific areas.

- *Actinide Chemistry:* Projects in this area are focused on providing fundamental information of the chemical behavior, solubility, and speciation of uranium, neptunium, plutonium, and americium in simulated alkaline tank waste sludges and alkaline scrub liquors. This information will support flowsheet development, process modeling, and safety assessments for waste storage, treatment, and disposal.

- *Analytical Chemistry and Instrumentation:* Directed-science projects focus on laser ablation techniques, mass spectrometry, and sensors and techniques, as applied to chemical and physical characterization of high-level waste in tanks and during processing. Studies of ablation mechanisms and the effect of the physical and chemical states of the sample (e.g., valance state, impurity concentration, particle morphology, defect concentration, and presence of liquids) on the character of the particles produced by laser ablation will help validate the LA/MS technology for quantitative chemical analyses. Development of an array of chemically selective sensors, based on highly selective molecular recognition agents and fluorescence techniques, coupled to fiber optics, will provide the bases for the safe and cost-effective in situ characterization techniques for tank wastes. Research into electrochemical techniques to explore the fundamental aspects of the general and localized corrosion behaviors of iron and carbon steel in alkaline environments will support tank corrosion and integrity assessments. A multi-organizational research task is developing new real-time sensors for characterizing glass melts in HLW and low activity waste (LAW) melters, and to understand the scientific basis and bridge the gap between glass melt model data and melter performance.

- *Engineering Science:* Investments are being made to develop the engineering fundamentals to address waste treatment and tank safety issues. A study is investigating interactions between gas bubbles and rheologically complex waste in order to improve accuracy of gas volume estimates in tank wastes, provide for more accurate estimates of waste properties from level/pressure data, and quantify the effect of pressure fluctuations on rise and release of bubbles. Fundamental studies and model development of aerosol agglomeration under the influence of acoustic and electric fields are being conducted to improve the understanding of how these methods could be used for aerosol abatement. Work is proceeding to develop a basis understanding of mechanisms including solid colloidal particles that cause foaming with specific application to foaming during waste treatment. Investigations are continuing to develop an understanding of the interactions among chemical reactions, waste rheology, and slurry mixing to provide a scientific basis for waste retrieval.

- *Geochemistry:* Investments in this area are specific to sorption and desorption research relative to HLW treatment and remediation, retrieval, and separation processes. Projects include providing a credible model for the release of radionuclides from residual sludge. Sludge components that are the prime actors in retaining radionuclides will be identified and synthesized.

- *Hydrogeology:* A study is underway to investigate the causes and extent of nonuniform flow in the vadose zone, and its effects on the migration of contaminants leaked from single-shelled storage tanks at Hanford.

- *Inorganic Chemistry:* Work is underway to understand the complex chemistry of wastes including non-radioactive components and specific radionuclides such as technetium. The kinetics of dissolution, precipitation, and scale formation involving aluminum-containing phases characteristic of tank wastes are being studied under conditions expected during waste storage, washing, and transfer. Studies are being conducted to understand the solution chemistry of technetium in the waste tank environment as well as the stability of technetium in various waste forms. Several projects are focused on developing 1) a fundamental understanding of organic aging, 2) a model that describes the thermal and radiolytic aging of organic compounds in high-level waste, and 3) a realistic simulant for studying radionuclide partitioning. Solubility measurements and spectroscopic characterization are underway to study the speciation, dissolution and redox reactions of chromium under conditions relevant to high-level waste processing. Studies of the chemical speciation of waste components under hydrothermal conditions is being investigated as it relates to waste vitrification.

- *Materials Science:* Under the materials science heading, there are four areas in which the directed research is focused, they are chemical and structural properties of storage materials, radiation effects on storage materials, surface chemistry, and waste materials. Work is underway to develop an understanding of the processes and mechanisms controlling alkali ion exchange and to correlate the kinetics with glass structural properties as a basis for developing more durable waste glasses and higher alkali waste loading. Thermodynamic data is being developed for waste components in order to better predict waste form composition, phase separation, and volatility. The influence of radiation on phase separation and crystallization in glasses is being studied. Alternative waste forms including zeolite-based forms for calcined wastes and forms for silicotitanates used to remove cesium from HLW are being investigated. A study is underway to develop an understanding of pitting corrosion of carbon steel in dilute alkaline salt solutions to better understand tank corrosion.

- *Separations Chemistry:* HLW directed research investments in separations chemistry are in four specific areas: catalyst chemistry and waste treatment, ligand design and ion-exchange, technetium chemistry and separations, and fission product extraction processes. Basic research in electrochemistry of materials for the ultimate goal of creating stable materials with large ion exchange capacity and selectivity for cesium. Separation of sodium hydroxide and other predominant sodium salts such as sodium nitrate from high-level alkaline tank waste is being investigated, as are electroactive ion exchange materials to remove anionic contaminants from HLW wastes and process streams. Fission product extraction process research investigates efficient extraction processes for removing radionuclides from high level waste enabling a reduction in volume of material to be transported to a repository.

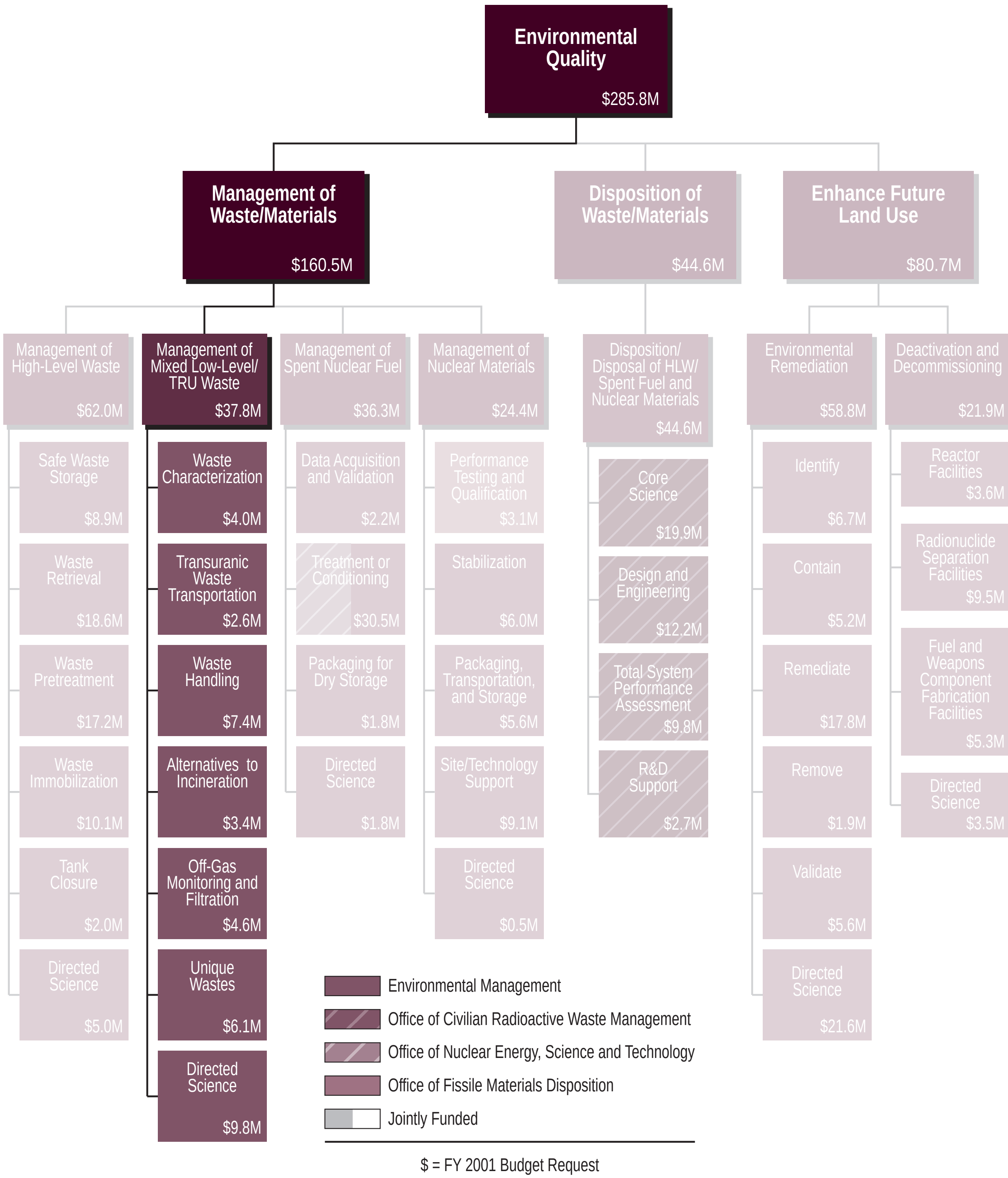
Budget Summary Table

(Dollars in thousands)

Program Activity	FY 1999 Appropriation	FY 2000 Appropriation	FY 2001 Request
Safe Waste Storage	5,955	6,180	8,941
Waste Retrieval	12,715	11,345	18,643
Waste Pretreatment	12,736	16,110	17,182
Waste Immobilization	11,150	10,360	10,134
Tank Closure	2,717	1,007	2,036
Directed Science	9,487	14,528	5,016
Total	**54,760**	**59,530**	**61,952**

Chapter 4

Mixed/Low-Level/Transuranic Waste



Chapter 4

Mixed/Low-Level/Transuranic Waste

Table of Contents

Overview

Definition of Problem Area

Thirty-six DOE sites are storing about 165,000 m^3 of mixed low-level and transuranic waste. More than 1,400 waste streams comprise this inventory, which is heterogeneous both physically and chemically. About 60% of the total inventory is categorized as transuranic and is packaged in a variety of containers ranging from 55-gal drums to fairly large cargo containers. Most of the transuranic waste (TRU) is destined for disposal at the Waste Isolation Pilot Plant (WIPP). Treatments for most of the inventory's mixed low-level waste (MLLW) portion are prescribed in Consent Orders, which were established between the sites and their host states in compliance with the Federal Facilities Compliance Act (FFCA) of 1992.

The Department projects that an additional 45,000 m^3 of transuranic waste and 170,000 m^3 of MLLW will be generated over the next ten years, primarily from environmental restoration and decontamination and decommissioning activities. For planning purposes, DOE assumes that the wastes generated in the future will possess physical and chemical characteristics similar to those in the present inventory.

Most TRU waste is the result of the weapons production process, and contains plutonium. TRU waste from weapons production results almost exclusively from fabrication of plutonium weapons components, recycling plutonium from production scrap, residues, or retired weapons, and chemical separation of plutonium. Considerable amounts of TRU waste also contain hazardous constituents subject to regulation under the Resource Conservation and Recovery Act (RCRA) or the Toxic Substances Control Act (TSCA). Since 1970,[1] the Department has placed TRU waste in retrievable storage, typically in metal drums or boxes, either on above- or below-grade storage pads, in buildings or in tanks. TRU waste, including a relatively small amount of non-weapons-related TRU waste, is managed at 21 sites. The Department plans to dispose of stored post-1970 weapons-related TRU waste at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Final disposition of non-weapons-related TRU waste is still being determined, since, by current law, non-defense TRU waste cannot be disposed at WIPP.

Mixed low-level waste contains chemically hazardous as well as (non-transuranic) radioactive materials. As such it is subject to regulation under both RCRA and the Atomic Energy Act . The Department first started managing mixed low-level waste as a separate waste type in the 1980s. It is generated during a broad spectrum of processes and activities including equipment maintenance, materials production, cleaning, environmental restoration, facility decontamination and decommissioning (D&D), and the treatment or handling of low-level waste and other waste types.

The storage, treatment and disposal of MLLW are subject to state and Federal regulations. In response to the Federal Facilities Compliance Act, a 1992 Amendment to RCRA, each DOE site managing MLLW developed a "Site Treatment Plan" for these wastes. These plans formed the basis for consent orders, which were negotiated with the sites' host states. Within the provisions

[1] Prior to 1970, most TRU waste was routinely disposed in shallow pits and trenches. Pre-1970 disposed TRU waste is addressed as part of Environmental Remediation, discussed in Chapter 8.

of the consent orders, the DOE sites are subject to various state-imposed penalties for missing mixed waste treatment and management milestones. Estimated costs for management and disposition of mixed, low-level, and TRU waste are shown in Figure 4-1.

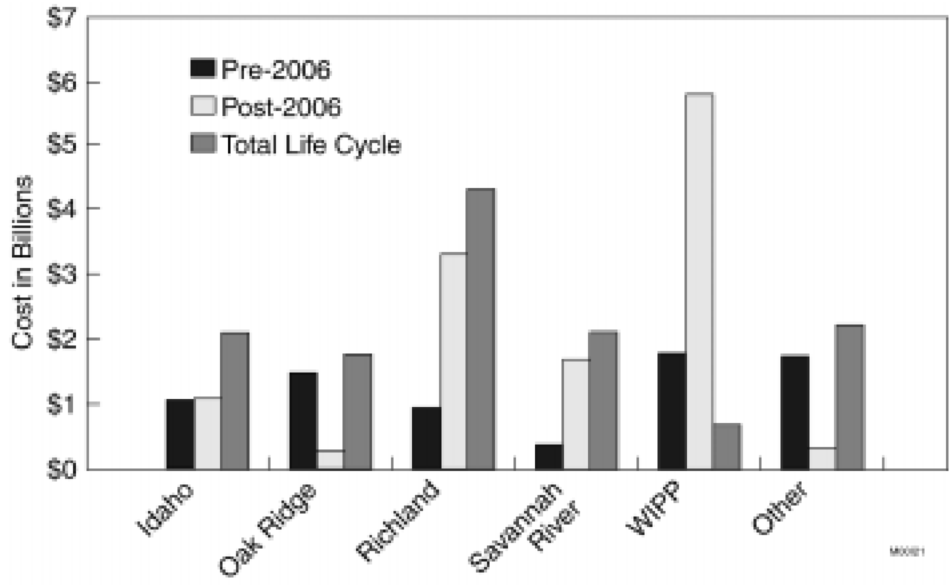


Figure 4-1. Through 2006, Post-2006, and Life Cycle costs for managing mixed, low-level, and transuranic waste.

National Context/Drivers and Federal Role

Currently, there are three principal drivers for the MLLW/TRU research and development portfolio: opening of the Waste Isolation Pilot Plant for TRU waste disposal; the consent orders in effect for MLLW; and the Environmental Protection Agency's promulgation of the rule, Maximum Achievable Control Technology for Waste Combustors (MACT).

The TRU waste to be shipped to WIPP must meet stringent waste acceptance criteria. The R&D portfolio is providing waste characterization and certification methods that are safer, more cost-effective, and quicker than currently available techniques. The portfolio also contains products that will improve the efficiency of the TRU waste shipping containers. If the technologies being developed fail to meet technical and schedule requirements, there will be significant impacts at several major DOE sites. Specific milestones in the Idaho settlement agreement and the Hanford Tri-Party Agreement will be jeopardized. Generally, less TRU waste will be shipped to WIPP and a greater number of shipments will be required for that which goes to WIPP. This will dramatically increase the total cost to DOE of shipping waste to WIPP and extend the timeframe for getting TRU waste out of storage and into safe disposal.

Missed consent order milestones cost money in fines and other penalties, and damage DOE's credibility with its host states. The MLLW/TRU R&D portfolio enhances DOE's ability to meet milestones and reduce the cost of compliance in several ways. The portfolio is providing safer, less expensive methods for characterizing the wastes' hazardous components and safer, more efficient methods to handle—especially--highly radioactive wastes in preparation for treatment.

The presence of mercury adds greatly to the cost and complexity of MLLW treatment. Technologies to separate and stabilize the mercury are being demonstrated. The portfolio is providing techniques to address small quantity, highly problematic mixed waste streams, which exist at virtually all major DOE sites. Altogether they comprise 10-l5% of DOE's total MLLW inventory, and most have no clear path to disposition. Ceramics, polymers and other revolutionary waste stabilization materials are being made available to the sites to improve the environmental performance of final waste forms. These alternative technologies also increase waste loading efficiency, reducing waste volumes disposed, which, in turn, reduces disposal costs and conserves scarce disposal capacity.

The Environmental Protection Agency's (EPA) MACT rule, which became effective in October 1999, will potentially reduce, if not eliminate, DOE's ability to treat MLLW by incineration. The loss of incineration capacity will threaten several DOE sites' ability to meet compliance agreements, including sites that intend to use the facilities as well as the sites that operate the facilities. In recent trial burns DOE's three incinerators, which are located in Idaho, South Carolina and Tennessee, failed to meet at least one emission or monitoring requirement contained in the proposed rule. Specific problem areas include mercury, dioxins and furans. According to the EPA's current schedule, the facilities will have to be in compliance by October 2002, or be shut down. The MLLW/TRU R&D portfolio is supporting development of emissions control and monitoring techniques that will allow the incinerators to comply with the new, more stringent regulatory requirements. Also, the portfolio contains alternatives to incineration (for some waste streams) for use at sites where incineration may not be possible due to state or local regulations, or stakeholder concerns.

The federal government, private sector, and universities all have roles in research and development for MLLW/TRU. Most of these wastes are managed within the DOE site operating system. For certain large volume, fairly homogeneous waste streams, where adequate profit potential exists, DOE has been able to engage the private sector in contracts that essentially privatize the waste treatment function. An example is the contract between DOE and British Nuclear Fuels Ltd Inc. (BNFL) to treat a large quantity of TRU waste prior to its shipment from the Idaho National Engineering and Environmental Laboratory (INEEL) to WIPP. The contract provides for some R&D by BNFL. The DOE is responsible for responding to technology needs identified by each of the major sites. The DOE's portfolio contains technologies from its laboratories, universities and the private sector. Technologies originally developed for application to strictly hazardous wastes often require only minor adaptation or demonstration for the wastes' radioactive component to broaden their applicability to mixed wastes.

Linkage to DOE Strategic Goals and Objectives

DOE delivers technical and engineering solutions necessary to ensure that MLLW/TRU program managers can resolve present and future needs identified in their accelerated path to closure. DOE is working to three key strategic objectives, which link directly to Environmental Quality goals and objectives. These objectives are to:

- Provide the science and technology needed to ensure safe, efficient characterization, certification, and transportation of TRU waste to the Waste Isolation Pilot Plant.
- Provide the science and technology needed to ensure DOE sites meet MLLW treatment consent orders in a timely, cost-effective manner.
- Provide the science and technology needed to maintain DOE's capability to treat MLLW by incineration in the face of increasingly stringent environmental regulations.

DOE invests in solutions that will be deployed and have a significant national impact. This is accomplished by an end-user-driven process that enables all steps from need identification through solution deployment, and is completed as an integrated part of the overall cleanup effort.

The portfolio's technologies help ensure safe, efficient characterization, certification, and transportation of TRU waste to the Waste Isolation Pilot Plant. These products directly support EQ Objective 3 to "safely and expeditiously dispose of waste generated by nuclear weapons and civilian nuclear research and development programs…" Other portfolio products help DOE sites meet MLLW treatment consent orders in a timely, cost-effective manner, and allow DOE to maintain the capability to incinerate MLLW in the face of increasingly stringent environmental regulations. These activities, too, are aimed at the EQ objective to make MLLW/TRU ready for safe and expeditious disposal. All the portfolio's activities are aimed at reducing the life-cycle costs of environmental cleanup by developing and deploying innovative technologies.

The level of impact and support the mixed/low-level/TRU waste activities provide to the Environmental Quality strategic objectives is indicated in Figure 4-2.

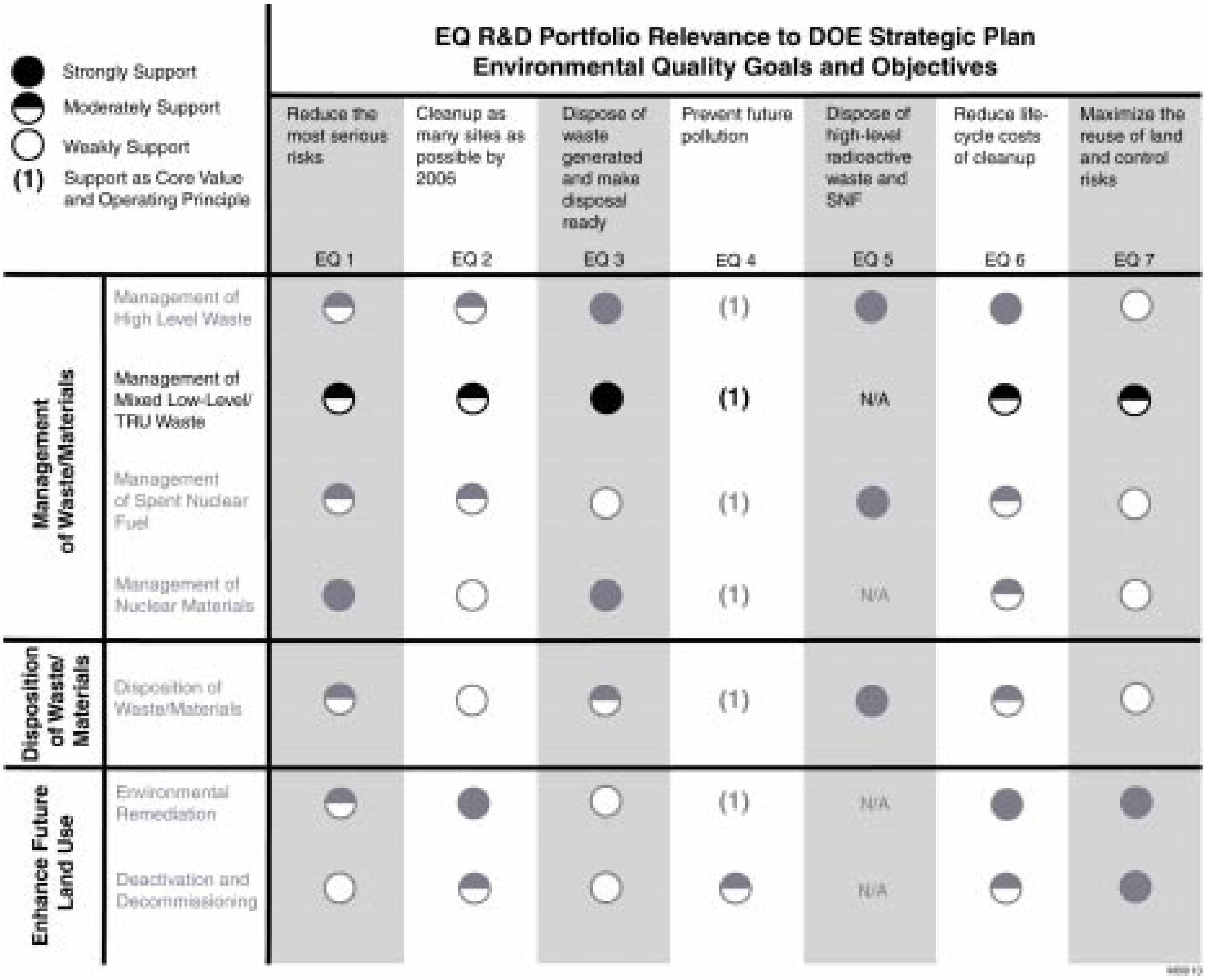


Figure 4-2. Relevance of mixed, low-level, and transuranic waste R&D investments to Environmental Quality goals and objectives.

Problem Area Uncertainties

This portfolio's most difficult technical challenges lie in the characterization of boxed and remote-handled TRU wastes. These waste streams present significant challenges to several current capabilities including adequate characterization, safe handling, adequate treatment to multiple requirements, and identification of available disposal facilities. High beta/gamma radiation fields create unique problems for non-destructive examination and assay techniques that may rely on less energetic radiation. Boxes are more problematic, because the magnitude of technical problems increases with container size. About half the TRU waste currently in storage is contained in the larger boxes, rather than drums.

Regulatory requirements affecting waste treatment facilities will continue to change. For example, the Environmental Protection Agency is considering replacing the toxicity characteristic leaching procedure (TCLP) with a suite of tests (that may or may not include TCLP) for hazardous waste characterization and compliance with Land Disposal Requirements treatment standards. Revision of the waste testing requirements could have a large impact on the volumes and types of waste categorized as mixed wastes. Such revisions could also impact requirements for mixed waste treatment and disposal and associated costs of the entire DOE mixed waste management system. An Advance Notice of Proposed Rulemaking is expected within the next year or two.

It is known that environmental restoration activities will generate additional quantities of MLLW/TRU. How much will be generated is not certain. An uncertainty with greater significance for science and technology resides in the specific MLLW/TRU waste streams that may be generated. Relatively large waste streams that are significantly different from those in the current inventory have the potential to present future "gaps" that will require new science and technologies.

R&D Investment Trends and Rationale

Figure 4-3 illustrates the current investment for mixed, low-level, and transuranic waste areas. The portfolio managers are undertaking the entire technology development process only in those cases where it is absolutely necessary. Over the past few years a series of Requests for Information (RFI) were issued in the Commerce Business Daily and other information media describing the problems to be addressed, and requesting responses from entities who believe they have a technology that might solve the problem. These RFIs successfully generated responses from universities, the private sector and DOE Laboratories. In many cases, the RFI process discovered technologies that need only minor adaptation or demonstration under specific conditions to be able to resolve certain MLLW/TRU problems.

Portfolio managers are investing the most significant share of their resources in the science and technology needed to certify and ship TRU waste to WIPP. Currently, these problem areas are the highest priority and the most difficult and expensive to resolve. Waste stabilization and waste form improvement to meet DOE's near-term needs are nearly complete, and emphasis is shifting to deployment.

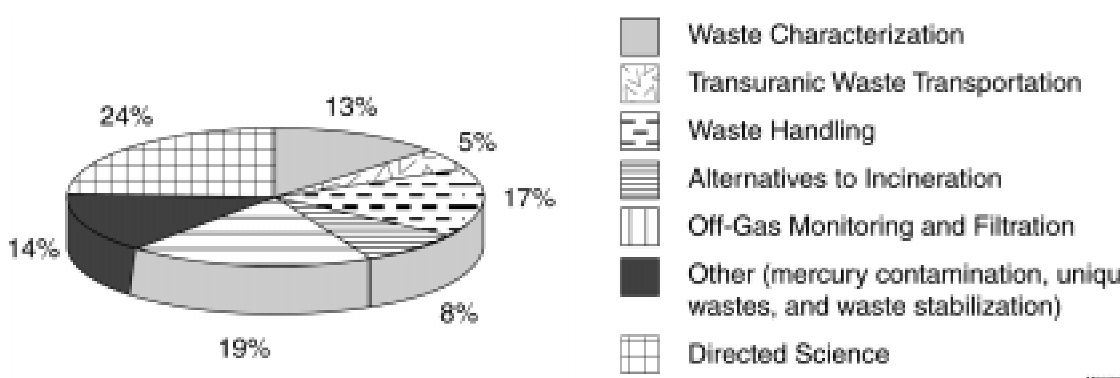


Figure 4-3. *Cumulative investment in mixed, low-level, and transuranic waste areas over 3 years (FY 1999–FY 2001).*

The sites' technology needs appear to be evolving beyond those that are similar or common among sites. Previously, allowing investment in a single technology, or suite of similar technologies, offered the possibility of solving several sites' problems. New and revised site needs, which were identified in the first quarter of FY 1999, are extremely heterogeneous; often, each need describes a unique problem specific to a particular site. Of the 136 site needs now applicable to this portfolio, about half are outside its current technical baseline capability. In the future, it may be more difficult for portfolio managers to find "big hitters"; that is, opportunities for single technology investments with a high potential for national impact and large cost savings or major project risk reduction. Generally, the number of needs in this area is increasing while budgets dedicated to resolving the needs are decreasing.

Key R&D Accomplishments

DOE has made significant progress in resolving the problems associated with managing its mixed low-level and TRU waste inventories. However, the portfolio has primarily focused on near-term system drivers: consent order compliance, moving TRU waste to WIPP, and meeting new, more stringent air emissions standards.

For current inventories of MLLW requiring stabilization, development of a suite of improved technologies is complete. Also complete are development and demonstration of technologies to treat mercury-contaminated mixed wastes. Often, these technologies are eliminating the sites' entire inventory of a mixed waste stream, finally putting an end to the life-cycle costs and risks associated with storing the wastes.

Work on improved nondestructive examination and assay techniques for contact-handled TRU waste drums is complete. The Active and Passive Computed Tomography technology is now providing mobile characterization services for TRU waste at the Nevada Test Site.

In 1999, several sites adopted newly developed standards for evaluating the performance of TRU waste nondestructive assay instruments. Also deployed was a new method for nondestructive assay of TRU waste radionuclide content. These technical solutions enable timely and efficient shipment of TRU waste to the Waste Isolation Pilot Plant for disposal.

DOE has completed development of a suite of waste stabilization technologies that collectively can address the entire Department's current mixed waste stabilization needs. With development complete, emphasis is shifting to deployment. Among the first completed, Polymer Macroencapsulation was deployed commercially in 1996 through a cooperative agreement that provided treatment and disposal of 520,000 lb of mixed waste lead and debris from 23 DOE sites. In several cases, the material processed was the site's entire waste stream. In one case, application of the technology eliminated a DOE site's entire mixed waste inventory. Two other DOE-developed stabilization technologies--polymer microencapsulation methods-- were commercially deployed in 1999. An advanced ceramic stabilization method will begin commercial operation in 2000. Availability of this suite of technologies will allow treatment of 85–90% of the DOE mixed waste streams presently requiring stabilization.

DOE and the private sector have successfully developed and demonstrated a suite of technologies for treating mercury-contaminated wastes. DOE sites are now acquiring the use of these technologies through contracts with the private sector, often allowing elimination of a site's entire mercury-contaminated mixed waste stream. Negotiations are under way to commercially deploy sulfur polymer cement, a DOE-developed technology proven to be very robust in treating mercury wastes. Collectively, this suite of technologies is able to process virtually all DOE's present mercury-contaminated mixed waste inventory.

DOE has completed all experimental and modeling activities aimed at increasing the amount of TRU waste that can be transported in the Transuranic Package Transporter, Model II (TRUPACT-II) shipping container. A significant portion of TRU waste destined for WIPP would require treatment or repackaging in order to be transportable. The portfolio's technical analysis and modeling results will be included in the shipping container's safety analysis report, which will allow up to 70% of the currently unqualified waste to be shipped without treatment or repackaging. Enabling these shipments will save DOE, and hence the taxpayers, $300 million.

DOE has successfully applied this portfolio's resources to unique mixed wastes, which are usually small-quantity, highly problematic mixed wastes that exist at many DOE sites. Two dozen projects have been initiated, resulting in elimination of more than 30 mixed waste streams at 14 DOE sites totaling over 538 cubic meters. At the Nevada Test Site (NTS), one such project eliminated a mixed waste stream that comprised 85% of the site's entire mixed waste inventory. The portfolio's alternative solution completed the job much quicker and at $1.25 M less than NTS's original estimate.

DOE has truncated its support of three high-temperature melters: the DC Arc, Plasma Hearth Process, and Transportable Vitrification System. The melters were originally envisioned as high capacity, "omnivorous" technologies, capable of converting a wide band of extremely heterogeneous waste streams into durable glass waste forms. Had these technologies been entirely successful, a few large systems could have treated most of DOE's MLLW inventory with need for relatively little pre-treatment handling and characterization. Vitrification technologies have proven to be extremely useful for treating high level wastes, which are well characterized and homogeneous in comparison with mixed low-level wastes. However, the melters were unable to entirely live up to their early promise for treating MLLW. Developers found that, for a variety of reasons, pre-treatment handling and characterization continued to be required, which greatly reduced melters' cost-effectiveness. It is likely that melters will ultimately occupy a niche in mixed low-level waste treatment, but not as large a one as originally envisioned. A commercially designed and built high-temperature melter, which is based on the DOE development work, is being deployed at Hanford. The melters' limited success in treating MLLW has required the portfolio managers to continue their investments in improved waste characterization technologies, as well as simpler, low-temperature waste stabilization technologies.

Important work has recently commenced to provide sites with the capability to remotely handle highly radioactive wastes for sorting, repackaging, and transport to treatment. HANDS-55, targeted initially for use at the Savannah River Site and then to be modified for use at other sites, will save $100 million in waste packaging and transportation costs at Savannah River alone.

Key R&D Issues

A report issued recently by the National Research Council identifies a number of key research and development issues, particularly for mixed low-level waste. (National Research Council. 1999. *The state of development of waste forms for mixed wastes*. Washington, DC: National Academy Press)

A major finding of the report is that no new classes of waste forms are required. Recognizing that no single waste form is appropriate for all wastes, the Council notes it is “unlikely that any totally new class of waste forms will be necessary to complete EM’s planned cleanup program.” (p. 98) As noted above, the portfolio managers have essentially completed development work on waste forms and are focusing on technical assistance to DOE sites for implementation and deployment (another aspect of the Council’s recommendation). Funding reductions are restricting assistance available, however, leaving much of implementation and deployment to site operations and the private sector.

Another recommendation is for the portfolio managers to continue to respond to technology deficiencies (needs). As noted above these needs have tended to concentrate in three primary driver areas associated with the cleanup: characterizing and preparing TRU waste to be shipped to WIPP; assisting sites in meeting Consent Order milestones; and new or improved monitoring and off-gas filtration technologies to allow DOE to continue incineration in the face of new, more stringent air emissions requirements. The nature of these drivers require action in the relatively near term—prior to 2006. The dedication of diminished resources to the near-term problems, however, allows little or no analysis to anticipate needs and deficiencies that may arise in the future.

New needs identified early in 1999 indicate sites’ attention is shifting to small quantity, highly problematic waste streams. These technology needs often require highly individualized solutions, applied to small waste streams. Because of the higher funding priority attached to technologies with broad application and large potential cost savings, portfolio managers have difficulty securing the funds to meet these technology needs.

Some longer-term challenges, which are extensions of the on-going work, can be identified. The portfolio managers, as well as the National Research Council, recognize the need for non-destructive characterization of hazardous substances in containerized wastes—heavy metals and organics in particular. Regulatory requirements affecting waste treatment facilities will continue to change. More restrictive requirements on facility effluents other than air—waste water, for example—can be anticipated. Preparing to meet more restrictive effluent emissions requirements with new or improved technologies presents a longer-term challenge.

A key research and development issue for this portfolio is the uncertainty discussed earlier regarding waste that will be generated by environmental restoration activities. While waste volumes have been tentatively predicted, less is presently known about the physical and chemical characteristics of the wastes. A fundamental assumption underlying management of the research and development portfolio is that the wastes generated in future cleanup activities will fit within the capability envelope of the technologies being implemented in the near term.

Problem Area R&D Program

Budget: FY99-$37.2M, FY00-$35.0M, FY01-$37.8M

Program Description

The MLLW/TRU portfolio of science and technology investments addresses all the major functions involved in managing these wastes. The portfolio's technical scope includes characterization, handling and repackaging, pretreatment and treatment, transportation, and disposal. The portfolio's solutions are applicable to legacy MLLW/TRU, which is currently stored at many DOE sites, as well as wastes being generated now and in the future as a result of on-going operations and environmental restoration activities.

Through analysis of the sites' submitted needs, DOE has identified eight major problem areas for the management of DOE's mixed low-level and transuranic waste inventory: waste characterization; transuranic waste transportation; waste handling; alternatives to incineration; off-gas monitoring and filtration; mercury contamination; unique wastes; and waste stabilization.

In the following sections, the problem areas are summarized along with the activities aimed at resolving them. The activities described in this section are present or planned for the near-term, and do not necessarily address the longer-term challenges and issues discussed above.

Waste Characterization

Budget: FY99-$5.0M, FY00-$5.4M, FY01-$4.0M

Description. Various regulatory drivers and management needs, as well as stringent WIPP acceptance criteria for transuranic wastes, require detailed characterization of the mixed waste inventory's radioactive and hazardous components. Sites characterize wastes using a combination of process knowledge, destructive analysis, and nondestructive analysis. Process knowledge on the stored waste streams may not provide the detailed data needed to meet current characterization requirements. Destructive analysis requires opening and drawing multiple samples from each container. This increases exposure risks to workers and the environment, and is slow, expensive, and generates secondary mixed waste streams. Available nondestructive examination and assay (NDE/NDA) techniques for contact-handled wastes alleviate some of these problems, but improved performance is needed to measure complex waste forms. Nondestructive examination and assay techniques to characterize remote-handled wastes must still be developed and demonstrated.

Objective. Improve end-users' capability to nondestructively examine and assay containerized waste for radioactive and hazardous components.

Strategy. The strategy to resolve waste characterization problems is based upon logical groupings of the problems areas identified. Three major categories have been created: determination of hazardous contaminants, determination of radioactive contaminants, and support programs.

Hazardous contaminant characterization identifies and quantifies RCRA constituents, process operating parameters, and the other physical and chemical properties that affect the system. It has been further divided into debris and sludges. This additional level of characterization is needed to address the differences in requirements and approach. Requirements for debris characterization are driven by the DOE incinerator criteria, and sludge characterization is driven by WIPP criteria.

Radioactive contaminant characterization is divided into contact-handled and remote-handled wastes due to the unique problems associated with remote-handled waste. These problems arise from the high beta/gamma and neutron backgrounds associated with the waste. Each category is further divided based upon the size of the waste package, because the magnitude of the problems identified earlier increases with package size. This allows for subsets of the problem to be resolved independently. In this strategy, contact-handled waste is given a higher priority than remote-handled waste and small packages are given a higher priority than large ones.

There are several reasons for this: it is easier to resolve the problems on contact-handled waste, and it is easier to resolve small package problems; there are more drums than boxes (although the volumes are approximately equal); and WIPP and site disposal schedules.

Support programs provide additional technical support and materials for the deployment and implementation of nondestructive assay technologies. Certified radionuclide standards and surrogate wastes are needed to assess technology performance.

R&D Activities:

Hazardous Contaminant Characterization—Solutions to determine hazardous contaminants will be based on non-destructive technologies. These will primarily rely on the interrogation of the waste container with a neutron source and subsequent detection of gamma rays. The detected gamma rays are the result of neutron reactions with hazardous contaminants that result in the emission of gamma rays. Other non-destructive technologies that employ x-rays as the interrogating radiation will be examined. The criteria and requirements that must be satisfied will be established by the waste acceptance criteria that are associated with the DOE treatment and disposal facilities. DOE will also address problems associated with conventional (that is, destructive) RCRA contaminant analysis.

Contact-Handled Wastes—To date portfolio managers have focused on developing solutions for the wastes contained in 55-gal and 83-gal drums. Advanced systems have been developed based on tomographic active and passive gamma-ray spectroscopy and active neutron measurements using thermal and epithermal neutrons. These systems have been shown to more effectively handle the identified problems and yield results with lower total measurement uncertainty. Additionally, a comparative demonstration of commercially available technologies was conducted. Requirements for future technology development activities are based on the results of this demonstration.

For boxed wastes, a baseline report documenting the need (waste types, quantities, radionuclides) and capabilities of current technologies has been completed. It is anticipated that the box assay systems will use all of the technology developed for drums to address the identified problems. Therefore, they will be based on active and passive neutron counting as well as active and passive gamma ray spectroscopy.

Remote-Handled Wastes—Potential solutions to address nondestructive assay of remote-handled wastes were identified in 1998. Each technology under evaluation uses a different approach to deal with high background gamma and neutron radiation, and was previously funded or evaluated by other DOE programs. The purpose of the present evaluation is to assess their potential to assay remote-handled transuranic wastes. The successful technologies will be further developed using commercial vendors with assistance from national laboratories directed by the vendor. Implementation will be led by the vendor and will be supported by DOE.

Support Programs—DOE is funding the development of surrogate waste drums and crates and standards to support testing of developmental and commercially available systems. These standards will contain radionuclides and RCRA hazardous materials.

Accomplishments. Deployment of the Combined Thermal/Epithermal Neutron Assay System was initiated in FY-99 at the Los Alamos National Laboratory. The project is scheduled for completion in FY-00 and will be used to characterize 55-gallon transuranic waste drums. An expert system to perform neutron data validation was demonstrated and QA completed in FY-99. Deployment at the INEEL is planned for April 2000 Design and fabrication of large particle plutonium, the highly enriched uranium, and the depleted uranium working reference materials was completed. Two B-25 crates and two sets of matrix modules, a wet combustible and a dry combustible, were designed and fabricated to represent boxed transuranic waste. These surrogates were deployed to support the development of a crate counter for Rocky Flats and a counter under development at LANL. A set of three waste surrogates were designed and fabricated to represent a remote-handled transuranic (RH-TRU) waste stream at the INEEL.

Transuranic Waste Transportation

Budget: FY99-$1.1M, FY00-$1.7M, FY01-$2.6M

Description. The Transuranic Package Transporter, Model II (TRUPACT-II) is the shipping package for CH-TRU waste, and the 72B cask is the shipping package for RH-TRU wastes transported to WIPP for disposal. Strict limits are in effect for flammable, volatile, and semivolatile gas concentrations in each waste package to ensure safety during transport conditions. As a result, 20–40% of the transuranic waste currently stored at 34 DOE and non-DOE sites cannot be certified for transport. Two options are available to sites for solving this problem: gas generation testing on each drum and waste form modification via repackaging and/or treatment. These options increase waste handling and transportation risks and their associated costs rise dramatically. Real waste-gas-generation data is needed to expand the acceptable payload envelopes of the shipping packages. Techniques are also needed to remove the problem gases from the waste packages before or during shipment.

Objective. Increase the container payload efficiency of transuranic waste shipments for treatment and disposal.

Strategy. DOE has developed a strategy (the TRUPACT-II Payload Expansion Plan) to address the flammable gas impact on transuranic waste transportation. This strategy is designed to expand the TRUPACT-II waste envelope and minimize impact on remote-handled transuranic waste. This strategy defines the hydrogen gas generation problem according to the following situations:

- Predicted to exceed 5% hydrogen gas concentration when actual hydrogen gas concentration is less than 5%.

- Exceeds the 5% hydrogen gas concentration limit.

These problem areas exist in both contact- and remote-handled transuranic waste. DOE assumes that solutions developed for contact-handled waste will be generally applicable to the remote-handled portion. Under this strategy, DOE is funding the collection of data that will be used in revising the TRUPACT-II Safety Analysis Report for Repackaging and the 72B Cask Safety Analysis Report for Repackaging.

DOE-funded programs will provide transportation relief for approximately 90% of the current TRUPACT-II hydrogen-gas-related drum rejections at the Idaho, Los Alamos and Rocky Flats Sites. The amount of relief anticipated for the higher Curie loading plutonium-238 waste stored at SRS has not been estimated due to a lack of inventory assay data.

R&D Activities:

Contact-handled Transuranic Waste—DOE is funding activities to address situations in which the contact-handled waste package is predicted to be greater than 5% hydrogen, when it is actually less than 5% hydrogen. These activities are directed at collecting gas generation data that are more representative of actual contact-handled transuranic waste and developing alternative methods of compliance with the hydrogen gas generation rate requirement. The activities to address the situation in which the hydrogen gas concentration is greater than 5% are directed at technologies that remove hydrogen gas from the TRUPACT-II payload.

These solutions will provide a basic understanding of the gas generation process and the mechanical/chemical treatment alternatives required to ensure the waste is transported to WIPP in a safe, cost effective manner. These activities, initiated between FY-00 and FY-02, are expected to provide significant cost savings and accelerated certification schedules for the sites.

Remote-Handled Transuranic Waste—DOE will support activities to address situations in which the remote-handled waste package is predicted to be more than 5% hydrogen, when it is actually less than 5% hydrogen. Currently funded activities are directed at collecting gas generation data that are more representative of actual remote-handled transuranic waste. Future work will include developing alternative methods of compliance with the hydrogen gas generation rate requirement. DOE will develop technologies that remove hydrogen gas from the 72B Cask payload for those situations in which the hydrogen gas concentration is greater than 5%.

Accomplishments. In 1998, DOE completed experimental and modeling activities centered on increasing the amount of TRU waste that can be transported in the TRUPACT-II shipping container. Of the TRU waste that is currently not transportable to the Waste Isolation Pilot

Plant, up to 70% will be transportable once results from these activities are incorporated in the shipping container's safety analysis report. Work was also completed to calculate drum age criteria for additional DOE waste streams. This reduces the time required to obtain acceptable headspace gas samples from transuranic waste drums.

Waste Handling

Budget: FY99-$6.0M, FY00-$4.7M, FY01-$7.4M

Description. DOE sites have expressed many needs for improved handling techniques for waste streams within the mixed waste inventory, especially those designated as remote handled. Planned treatment and disposal methods demand new or improved technologies for repackaging or sizing wastes, and moving or handling wastes at the treatment or disposal facility. According to the National TRU Waste Management Plan, about 35% of the TRU waste volume in storage has handling issues related to its safe treatment and repackaging. Some commercially available technologies can be used for wastes designated as contact handled, but these require adaptation to reduce worker exposure. Technologies applied to remote-handled wastes are much more complicated to operate and maintain, requiring separation of the workers by containment.

Objective. Provide the capability to remotely handle highly radioactive waste streams for sizing, repackaging, and transport.

Strategy. The strategy for resolving this problem centers on four key waste handling functions: repackaging, sizing, retrieval of stored waste and transportation to treatment.

The focal point of the present strategy is to provide technology that will meet repackaging needs to transfer waste to WIPP. The repackaging technology will be demonstrated using contact-handled waste that requires containment for alpha contamination. This technology is being designed in a remote modular format for ease in adapting it to a mobile platform for small generator sites, or fully automated for remote-handled waste. Another development area is sizing or volume reduction of remote-handled wastes. Many sites have large pieces of remote-handled waste that must be size-reduced to meet disposal criteria, volume reduction by segregating, or to prepare the waste for the designated treatment method. This work will focus on adapting commercially available sizing technology rather than development. Treatment methods for mixed wastes, both contact-handled and remote-handled are ready for deployment; therefore, the issues associated with transporting waste to treatment must be addressed.

R&D Activities. DOE is developing a system (HANDSS-55) to prepare drummed transuranic and transuranic mixed wastes that are stored at SRS for transport to WIPP. This semi-remote system will open drums and liners, remove non-compliant items, and repackage the waste into WIPP approved storage containers. The SRS has approximately 30,000 drums that need this form of preparation and verification to meet WIPP acceptance criteria. But other sites, such as Los Alamos and Hanford, have also listed repackaging for WIPP as a high priority need. HANDSS-55 is being designed in a modular format to adapt the system to be a mobile platform, to meet the needs of the small generators (Mound and Battelle Columbus), or to allow the system to be fully remote automated for future use on remote-handled waste.

The National Transuranic Program has listed developing robust sizing technology for remote-handled waste as a high priority technology development area. This investment will adapt commercially available technology to meet the remote sizing needs at Richland and SRS.

This investment also addresses the transportation issues associated with moving non-homogenous wastes to treatment methods. Currently this investment provides a solution to a fly-ash transport problem for the Idaho Ash Demonstration. Using this commercially available technology in an innovative way will help increase process reliability and reduce worker exposure to hazardous and radioactive constituents. The SRS has also listed a reliable transport and ash stabilization process as a need.

Portfolio managers are also investigating the DOE Complex-wide needs for automated retrieval of containerized waste that was not previously intended to be recovered. Currently there are two documented needs for this type of retrieval at Hanford, and other DOE sites anticipate having a need for this technology in the future. This development area is being jointly investigated with the Roadmapping for Intelligent Machines (RIM) Program.

Accomplishments. This was a new investment in 1998, with technology development starting in the area of repackaging TRU waste for transfer to WIPP. During FY-99 the Handling and Segregating System for 55 gallon drums (HANDS-55) started development for the end user of the system at the Savannah River Site. HANDS-55 is a semi-remotely operated system that opens 55-gallon drums of Pu-238 & Pu-239 job control waste, removes non-compliant items and repackages the waste into polyethylene containers sized to fit into standard 55-gallon drums. During FY-99 the automated drum and liner was demonstrated and the infrared welding technique needed to seal the polyethylene canisters proven. Development will continue in FY-2000 with demonstration of the sorting technique and the polyethylene canister and sphincter seal.

Alternatives to Incineration

Budget: FY99-$3.1M, FY00-$2.4M, FY01-$3.4M

Description. A portion of DOE's mixed waste inventory containing organic materials is difficult to stabilize; therefore, oxidizing or destroying the hazardous organic materials is preferred before final treatment for stabilization. The presence of certain nonorganic substances (for example, mercury) in the waste can eliminate incineration as a choice for organic destruction. Incinerators are becoming more complex, difficult, and expensive to permit and operate in both the DOE complex and the private sector. These combined technical and stakeholder considerations drive needs for alternative methods to oxidize organic materials in the waste. Alternatives to incineration can substantially reduce offgas emission volumes and eliminate the discharge of hazardous volatiles to the environment.

Objective. Provide non-flame alternatives (which can be thermal or nonthermal) to incineration for organic waste destruction.

Strategy. The strategy to resolve these problems involves two areas: solution development and solution deployments.

Solution Development—DOE has supported several alternative oxidation technologies as either developmental projects, or quick wins dedicated to rapidly deploying a technology on a small scale while eliminating one or more problematic waste streams. Examples of these technologies include Acid Digestion, Direct Chemical Oxidation, Catalytic Chemical Oxidation, Delphi Detox, and steam reforming. Although the development stage among these selected technologies varies greatly, several candidates are now at a level requiring a significant infusion of capital to attain the next level, namely a semi-scale or full-scale demonstration facility.

Solution Deployment—The strategy is to deploy one or several of these technologies at a given site to address a particular need. This strategy focuses on a competitive bid process to select and demonstrate a technology for treating plutonium-238 contaminated debris at SRS.

R&D Activities. The SRS has a need for a process to destroy the organic component of a combustible debris mixed waste stream known as job control wastes. This waste stream includes personal protective equipment, rags, plastics, and wood. This material is also contaminated with sub-micron plutonium-238 particles. Shipping waste to WIPP requires destroying the organic fraction to minimize or eliminate the radiolytic generation of hydrogen, or repackaging, which would be prohibitively expensive. Responding to this need is an ideal opportunity for the Alternative Oxidation Technologies, with the potential to reduce costs substantially, while demonstrating a technology that may be useful at many other sites needing non-incineration options. DOE is working to define technical performance requirements, selection criteria, and specific work activities. The project is estimated to take four years to successfully demonstrate technology that could then be deployed at other sites, and may be useful in the unique wastes requiring oxidation without incineration.

Accomplishments. During 1998, DOE completed development of two alternative oxidation technologies, Direct Chemical Oxidation (DCO) and Acid Digestion, and Innovative Technology Summary Reports were published on these processes in 1999. Both technologies are in the process of being commercialized and DCO will be offered by a private sector company in the Oak Ridge Broad Spectrum mixed waste treatment contract. Also, a catalytic chemical oxidation system was deployed at Lawrence Berkeley Laboratory to treat aqueous waste containing tritium, and the Delphi Detox catalytic oxidation system will be demonstrated and utilized to treat PCB waste at the Los Alamos National Laboratory. The Savannah River site in 2000 will be evaluating various DOE developed alternative oxidation techniques for treating a portion of their TRU waste as required to ship to WIPP.

Off-Gas Monitoring and Filtration

Budget: FY99-$8.9M, FY00-$7.8M, FY01-$4.6M

Description. In trial burns, the DOE's three incinerators, located in Idaho, South Carolina, and Tennessee, and Idaho's high-level liquid waste calcining facility, failed to meet at least one emission or monitoring requirement in the EPA's proposed MACT rule for Hazardous Waste Combustors. Specific problem areas include dioxins and furans, multi-metals, mercury, and other substances (e.g., chlorine). The rule was published as final in October 1999; therefore, the facilities will have to be in compliance by October 2002. If the facilities cannot meet the new requirements, they will be forced to shut down, which will threaten several sites' ability to meet compliance agreements. The loss of incineration capability would affect not only the site that operates the facilities, but also others that intend to use the facilities to treat their wastes.

Objective. Improve off-gas monitoring and environmental performance of the DOE's waste incinerators to meet new regulatory requirements.

Strategy. The strategy to resolve the problems associated with monitoring and controlling emissions is based upon logical groupings of problems: emission monitoring and emission control. The strategy consists of two primary thrusts: (1) working with regulators to understand the content and intent of newly proposed and forthcoming regulations, and to help ensure that those regulations are achievable, and (2) to work with facility operators to understand how regulations will affect them and to develop technological solutions for those facilities that may be unable to meet some aspect of a new regulation.

R&D Activities:

Emission Monitoring:

Dioxins and Furans Monitors—Monitors will be developed, through laboratory and commercial solicitation, to measure dioxins or indicator species which may be easier to detect. Correlations will be developed relating indicator or precursor species to the dioxin/furan toxicity equivalence. However, because this is likely to be a very sophisticated (costly) instrument, it will be used as a research or diagnostic tool, not as a compliance monitor. An alternative would be needed for a compliance monitor.

Mercury Monitors—Commercially available mercury monitors will be tested at DOE facilities to determine their effectiveness in off-gas systems that remove particulate and acid gas. Innovative mercury continuous emissions monitors will be developed and tested.

Multi-metals Monitors—Multi-metals continuous emissions monitors will be developed and tested using laboratory or commercial entities.

Other Monitors—Chlorine and hydrogen chloride continuous emissions monitors will be tested.

Emission Control:

Dioxins and Furans Control—In conjunction with the dioxin and furan continuous emissions monitors development effort, DOE's incinerator off-gas will be analyzed to determine the primary source of dioxin and furan emissions. Prevention and control measures will be developed and tested when the source of dioxins is better understood.

Mercury Control—Novel and commercially available mercury control technologies, such as gold filters and sulfur-impregnated carbon, will be tested to determine their effectiveness. Technologies for removing mercury from aqueous scrub solutions will be tested in coordination with work being undertaken by the mercury control product line.

Other Emissions Control—Technologies that remove high-levels of nitrogen oxides will be demonstrated. Techniques, including feed additives and control equipment, for controlling chlorine and hydrogen chloride emissions will be demonstrated.

Accomplishments. In 1999, DOE performed analyses of the Consolidated Incineration Facility to determine point of formation of dioxins/furans in the offgas system, so that appropriate control measures can be implemented. SRI International began development of a new emission monitor capable of near real-time measuring trace quantities of dioxins and furans. The Oak Ridge Site demonstrated the applicability of a commercially-available mercury monitor to the Toxic Substances Control Act Incinerator.

Mercury Contamination

Budget: FY99-$1.3M, FY00-$0.0M, FY01-$0.0M

Description. Mercury is present in a broad range of concentrations in several of the DOE's mixed waste streams, including large volumes of soil and debris, and several types of process residues. Because it is highly mobile and easily vaporized, the presence of mercury complicates the design of off-gas systems, the stabilization of treatment residues, and the monitoring of all effluents. Removing mercury before treatment would significantly simplify downstream treatment operations, thereby reducing the cost of treatment facility design, construction, and operation, as well as the risk of operation. After its removal, the mercury must be amalgamated, or otherwise stabilized, for disposal as a separate waste stream. Note - FY 2000 and 2001 funding for R & D activities associated with this problem area is included in Unique Waste problem area budgets.

Objective. Improve DOE's efficiency in managing mercury as a mixed waste contaminant.

Strategy. The strategy to resolve the problems associated with mercury waste streams is based upon logical groupings of the problems: mercury amalgamation, mercury stabilization, and mercury separation and removal. The strategy for addressing the mercury-contaminated waste problem started with forming the Mercury Working Group, comprising site end users responsible for treating mercury waste streams. The Mercury Working Group was asked to define the mercury mixed waste inventory and provide direction in selecting or developing technologies to address the problem. DOE issued a request for information through the Commerce Business daily to determine the current capabilities of the commercial sector. An analysis of the responses to the request for information, coupled with available waste inventory information and EPA treatment requirements, indicated that the mercury treatment technology selection and development strategy should be divided into three areas: amalgamation, stabilization, and separation.

Mercury Amalgamation—DOE issued a request for proposal from industry to demonstrate commercial processes on a larger scale using actual mixed waste streams. The request for information results indicated that industrial technologies were mature enough that, with a little more work, commercial processes would be available to treat DOE's wastes. Funding commercial demonstrations would provide the impetus for industry to put sufficient effort into their technologies to have them available. Also, because of the small quantities of waste at most sites, DOE needs to ensure that a vehicle is available for sites to combine their waste streams for treatment.

Mercury Stabilization—For the mercury stabilization area, a strategy similar to that employed for amalgamation was adopted for wastes contaminated with less than 260 parts per million mercury. In addition, efforts have been combined with EPA to investigate the possibilities of extending stabilization as a means of treating wastes contaminated with greater than 260 parts per million mercury. Demonstrations would be required to produce data to support that change.

Mercury Separation and Removal—For removing mercury from contaminated matrices, technologies other than retorting or roasting are not available. DOE turned to its laboratories to develop non-thermal methods for extracting mercury and has pursued commercial vendors to develop non-thermal treatment systems.

R&D Activities:

Mercury Amalgamation—Contracts were awarded to ADA Technologies, Inc., and to Nuclear Fuel Services. Quantities of radioactively contaminated elemental mercury were shipped to these vendors for treatment. In addition, the Mercury Working Group facilitated the issuance of a nationwide contract for mercury amalgamation of small quantity waste streams from multiple sites.

Mercury Stabilization—Contracts were placed with International Technologies, Duratek, Allied Technologies Group, and Nuclear Fuel Services to perform a variety of tests to demonstrate the capabilities of the commercial sector. These tests on less that 260 parts per million mercury matrices included bench-scale surrogate work with selected species of mercury and large-scale demonstrations on actual mixed wastes. National contracts will be made available to treat and dispose of less than 260 parts per million mercury wastes. Additional stabilization tests are planned for matrices with greater than 260 parts per million mercury. DOE is working closely with EPA to ensure that the data gathered in the tests will satisfy EPA's needs for evaluating proposed modifications to treatment requirements. As part of this testing, new EPA waste-form-evaluation protocols will be investigated.

Mercury Separation and Removal—Both DOE and commercial groups are developing and demonstrating mercury separation technologies. The technologies target industrial mercury in wastewater and in matrices destined for incineration, including soft debris and organic liquids.

Accomplishments. In 1998, DOE supported demonstrations of four mercury-waste stabilization processes where industrial partners treated waste containing less than 260 parts per million mercury. Allied Technology Group, International Technologies, Inc, and Nuclear Fuel Services stabilized surrogate waste in a series of tests with several species of mercury, and in 1999 DOE issued a technical report summarizing results. GTS Duratek, Allied Technology Group, and Nuclear Fuel Services stabilized actual waste. In 1999 portfolio managers issued technical reports on these technologies indicating their readiness for implementation. Two technologies were tested to remove mercury from East Fork Poplar Creek at Oak Ridge.

Unique Wastes

Budget: FY99-$2.0M, FY00-$5.4M, FY01-$6.1M

Description. Approximately 10–15% of DOE's mixed waste inventory cannot be prepared for disposal using existing capabilities. Reasons for this include the nature of the hazardous contaminants, radioactive isotopes present and/or their concentrations, regulatory requirements, stakeholder concerns, and resource limitations. These problematic wastes include organic or highly energetic waste streams, radioactive sources, and other miscellaneous, problematic streams. Because their disposition requires highly specialized solutions, they are not typically being included in the scope of privatized treatment contracts. Their usually low volumes and special problems have kept them in relatively low priority for disposition at most sites. However, at 10–15% of the total, they represent a significant proportion of DOE's mixed waste inventory. The potential accumulated costs of maintaining safe storage for these wastes warrants DOE's efforts to find solutions for their disposition. Note - FY 2000 and 2001 budgets for this problem area include funding for R & D activities directed at Mercury Contamination and Waste Stabilization problem areas.

Objective. Provide specialized solutions for small-quantity, problematic mixed waste streams.

Strategy. The strategy to resolve the problems associated with the small quantity, problematic waste streams is based upon logical groupings of the problems: organic waste streams, high energetic waste streams, radioactive sources and problematic waste streams.

Organic Waste Streams—DOE will provide end users with the necessary information to select those technology solutions potentially suited for their organic waste streams. In addition to needs identified by the sites, DOE has used site visits, workshops, and teleconferences to collect and clarify the needs associated with these waste streams and to define the requirement sets for the solution. Identifying these waste streams started in 1999, with the work continuing through 2003.

Highly Energetic Waste Streams, Radioactive Sources, and Problematic Waste Streams—DOE will develop national strategies for each element (using national initiatives, case-by-case resolution, and multiple-site coordination), to establish a National Initiative to address water reactive wastes. Developing the Highly Energetic Waste Stream Strategy is scheduled to start in 2000, and continue through 2002. Developing the Radioactive Sources Strategy is scheduled to start in 2000 and continue through 2002 and developing the Problematic Waste Stream Strategy is scheduled to start in 2000 and continue through 2004.

R&D Activities. To address these needs, portfolio managers will collect inventory data on problematic wastes, evaluate options and alternatives, and work with subject matter experts throughout the DOE complex to develop disposition strategies for these waste streams. Available funding will be utilized to perform treatability studies and deploy technologies to address the unique waste needs. These will be directed RFPs, based on the data collected and resulting strategic decisions developed through the collaborative efforts of several DOE organizations and site contacts.

Accomplishments. DOE developed the strategy, technical objectives, and work packages in 1998 and 1999, based on an analysis of similar small-quantity waste streams present at nearly all of the major and minor DOE sites. The solution-development process will begin in 2000, dependent on the availability of technology development resources. Despite a limited development budget in 1999, DOE portfolio managers were able to complete limited but successful technology demonstrations and deployments in this area. A technology to remove excess nitrates from wastewater streams at Los Alamos was deployed at a small scale and a method to stabilize Uranium chips was demonstrated at Hanford.

Waste Stabilization

Budget: FY99-$0.6M, FY00-$0.0M, FY01-$0.0M

Description. Portland cement is the baseline stabilization technology used for much of the sludge, soils, and homogeneous solids that comprise DOE's MLLW inventory. But waste streams produced as fly ash or scrubber blowdown residue from the DOE's incinerators present unique problems because they contain salts or heavy metals. These materials in sufficient quantities can prematurely degrade the waste form. This problem is currently resolved by mixing very low proportions of the waste material with the Portland Cement. This practice significantly increases waste volume, which then increases waste handling and transportation costs, and consumes scarce disposal capacity. Alternative stabilization technologies are needed that can maintain waste form integrity at higher waste loading. Note - FY 2000 and 2001 funding for R & D activities associated with this problem area is included in Unique Waste problem area budgets.

Objective. Increase the efficiency of waste stabilization processes, and improve the environmental performance of the resulting waste form.

Strategy. The strategy to resolve the problems associated with stabilizing high salt content and ash waste streams is based upon logical groupings of the problems: salt waste streams and ash waste streams. Portfolio managers will provide end users and waste managers across the complex with the necessary information to select those technology solutions potentially suited for their specific salt, ash, and/or problematic waste streams. DOE has developed and demonstrated new stabilization materials based on innovative chemistries (such as ceramics and polymers) to increase waste loading and improve final waste form performance for salt and ash waste streams.

DOE will complete the follow-up development efforts and demonstrations necessary to deploy the end-user chosen technology. However, no new classes of waste forms will be developed.

R&D Activities:

Salt—Five processes were tested using the same high salt waste surrogate composition: phosphate bonded ceramic stabilization, polyester stabilization, enhanced concrete, polysiloxane stabilization, and sol gel stabilization. The data from these tests, when published in the near future, will provide DOE with performance data on potential solutions to their high salt content waste streams.

Ash—Three processes were tested using the same incinerator mixed waste fly ash stream: phosphate bonded ceramic stabilization, sintered aggregate ceramic stabilization, and sintered monolith ceramic stabilization. The data from these tests, when published in the near future, will provide DOE with performance data on potential solutions to their ash waste streams.

Deployment—The SRS is conducting treatability studies on two processes to validate an efficient stabilization process for both the fly ash and the salt blowdown from their Consolidated Incineration Facility. The project started in 1998, and work will continue through 2000.

Disposal Criteria—If the new Environmental Protection Criteria are issued in 1999, testing waste forms to meet this criteria is scheduled to start later the same year.

Accomplishments. In 1998, DOE completed technology transfers and full-scale version deployments of Argonne's Chemically Bonded Phosphate Ceramic process and Brookhaven's Kinetic Mixer and Polymer Microencapsulation processes. Both of these methods are now being deployed at the Envirocare of Utah facility to treat DOE mixed waste. Based on completed development and demonstrations, DOE also issued Innovative Technology Summary reports on the following stabilization methods in 1999: the Sol-Gel Process, the Polysiloxane method, enhanced concrete, polyester and Clemson's sintering process.

Directed Science

Budget: FY99-$9.1M, FY00-$7.5M, FY01-$9.8M

Within the MLLW/TRU investment portfolio, DOE funds research that advances science to solve environmental problems associated with very limited treatment options and disposal capacities. Seven subcategories of needs were identified in the area of MLLW/TRU:

- Non-intrusive, nondestructive characterization, monitoring, and measurement.
- Reduction of waste volumes from remediation, decommissioning, and separations processes.
- Waste treatments for heavy metal, dioxin, organics, and radionuclide contamination.
- Shipping and storage of wastes, including hazardous and radioactive materials.
- Materials stabilization, including improved methods for predicting partitioning performance of vitrification techniques.
- Development of waste forms having long-term durability.
- Long-term behavior of different waste disposal forms and containment media.

The MLLW/TRU directed research portfolio is concentrated in 9 scientific areas (below). Portfolio managers periodically review the applicability of the projects presently identified in light of changing priorities and needs. Some of the projects listed here may no longer be applicable, while other science needs have arisen that are not yet being addressed.

- *Actinide Chemistry:* The objective of this research addresses the synthesis of new materials, the physical characterization and evaluation of those materials, and the evaluation (and subsequent improvement) of these materials for interface to applied separation technologies.

- *Analytical Chemistry and Instrumentation:* Focus is on mass spectrometry, and sensors and techniques. Develop sensors or waste treatment techniques that will assist with: monitoring of effluents; nondestructive characterization methods; development of inorganic processes to treat radionuclide-bearing wastes; characterizing metal/water interactions; molecular recognition strategies for toxic metals and organics, (i.e., lead, uranium, plutonium); and, development of a new class of chemical sensing technology for remote diagnostics of chemical species in hazardous gas, liquid and semi-solid phases.

- *Engineering Science:* Research projects will provide knowledge in the areas of bubble mechanics and sonification, and design, process and modeling for the handling, characterization, and treatment of TRU and mixed low-level wastes. Projects range from developing an understanding of reactions of organic compounds in the presence of high intensity ultrasound, to providing accurate predictive models for hazardous chemical and mixed waste properties.

- *Inorganic Chemistry:* Focus is on hydrothermal oxidation, multiphase/gaseous chemistry, and solid/solution chemistry. Applications for this work include knowledge that can be used to directly give reasonable estimates of explosive or flammability hazards in the storage or transport of transuranic wastes; reducing the volume of waste requiring vitrification and long term storage; quantifying and monitoring the presence of alkali metals and other elements in waste liquids; and, interpreting and predicting pathways (stoichiometric and catalytic), for the safe destruction of halocarbon pollutants.

- *Materials Science:* Focus is on two main areas, chemical and structural properties of storage materials, and surface chemistry. Projects include use of solar energy to oxidize organic chemicals to carbon dioxide and dilute mineral acids, thus reducing toxic pollutants with a very energy efficient detoxification method; and structure-property relationships for iron phosphate glasses that are of critical importance to cost-effective nuclear waste disposal.

- *Separations Chemistry:* Directed research is being conducted in catalyst chemistry and waste treatment, and ligand design and ion exchange. Investments will help meet challenges in MLLW/TRU material handling and characterization, and waste separation and treatment. Projects include removal of tritium from water, based on effects in the catalytic redox processes; development of electrochemical filtration and collection devices to be used for removal of heavy metals, radionuclides and transuranic elements from liquid phase streams; use ligands in the service of separations science; and, the solubility and stability of metal chelates in supercritical CO2 and use that understanding to model and compute phase behavior.

The next three research areas are applicable to several waste types, including waste types discussed in other chapters. The research is described here due to its high degree of applicability to the waste types discussed in this chapter.

- *Transport Aspects of Selective Mass Transport Agents:* The ability to separate radioactive and/or hazardous waste components from bulk matrices is a critical need in the efforts to cost effectively treat and process the wide variety of wastes for which DOE EM is responsible. The critical issues are 1) the physical characteristics of the separation media and 2) the inter- and intra-molecular interactions involved in the transport/retention mechanisms. Better understanding of these two areas will provide the basis for the development of new separation tools for DOE use. This effort consists of three research tasks.

  – Selective Mass Transport in Polymers. Studies of selective mass transport in polymers will be conducted including (1) Synthesis of polymer materials utilizing group contribution theory to predict desired material properties; (2) Physical property characterization of the synthesized polymers will be conducted and will include determination of glass transition temperatures, melting/degradation characteristics and other fundamental physical properties; and (3) Evaluation of interactions leading to transport of molecules in polymer matrices. Based on these activities a feedback loop will be provided that allows the optimization of the mass transport properties based upon understanding of the separation mechanisms. Polymers were chosen as the media of interest due to their potential use in encapsulents, liners, barriers, membranes, solid phase extractants, and other separation media. Targeted areas of study include application of positron annihilation spectroscopy (PALS), nuclear magnetic resonance (NMR) spectroscopy, electronic impedance spectroscopy (EIS), gas sorption and transport studies, and other standard polymer characterization techniques to understand the fundamentals of molecular interactions in the selected systems.

  – Pore Size and Morphology Control for Solid and Polymer Matrices. Understand methods for generating controlled pore sizes in polymers and in solid matrices such as silicates and aluminates. The ability to understand mechanisms of controlled pore size generation will permit the design of selective separation media engineered to accomplish specific separations of importance to DOE EM. Studies will be conducted with glassy polymers and micellular-forming materials to generate controlled pores. These studies include the development of molecular composites (i.e. polymer silicate) that will have specific molecular recognition and stability properties that could find applications in a number of separations areas. A variety of materials will be examined. Chemical templating methods will also be explored relative to production of controlled pores in the solid phase materials.

   - Adsorption and Absorption Materials for Molecular Separations. Development of new adsorption and absorption materials that possess enhanced selectivity for gas and liquid separations compared to currently available materials. Activities focus on specific surface and pore modifications to provide hydrophilicity or hydrophobicity plus molecular recognition. Materials of interest of these studies include sorbents specifically designed to absorb acid gasses (H_2S, SO_2, CO, CO_2), metal vapors (Hg), and water vapors.

- *Characterization Science:* Characterization methods are critical in waste remediation, handing, and processing activities. The program focuses on five areas: 1) intelligent nonintrusive methods, 2) adaptive sensors, 3) integrated sensors for in situ chemical measurement, 4) nondestructive assay, and 5) nuclear structure.

   - Intelligent Nonintrusive Methods. Characterization of nuclear material and containers is critical to the success of retrieval, processing, transporting, interim storage, and ultimate disposal of that material. The goal of this task is to provide sufficient understanding of the physical measurements to develop methods for processing and integrating information in order to automate decision making with respect to each characterization step (retrieve, process, transport, treat, store, dispose).

   - Adaptive Sensors. Substantially improve in situ measurement capability by exploitation of a new sensing technique based on nonlinear optics. The potential gain is a new class of noncontacting sensors that are self-adaptive, self-processing and provide quantitative images in situations where only point measurements are now available. Optical characterization has historically provided high quality characterization in the laboratory, but the need for sample preparation and other control has limited in situ application.

   - Non Destructive Assay (NDA). Radio-assay signatures for elemental identification and quantification. In particular, processes that are germane to complex wide NDA issues; i.e., actinide, fission product, and activation product identification and quantification.

   - Nuclear Structure. Perform nuclear structure research that build and expand current nuclear physics expertise. Four related research areas will be explored. All four address the need to improve the known nuclear data to either (1) verify and validate our present understanding of nuclear structure and the interactions of radiation with matter, or (2) to provide a foundation to be used to improve our current understanding of and ability to predict nuclear parameters such as energy levels, transition probabilities, etc.

- *Computational Simulation of Mechanical and Chemical Systems:* Delivery of computational modeling capability and results for chemical and physical processes that occur in the wide range of systems of importance to DOE EM.

- Computational Infrastructure. Provide computing infrastructure technologies for the efficient simulation and modeling of the computational components of environmental problems. These shall include support for all the elements of the computational work including physical and process simulation, data analysis and archiving, and the appropriate visualization and communication tools. This effort will develop multi-processing computing capability.

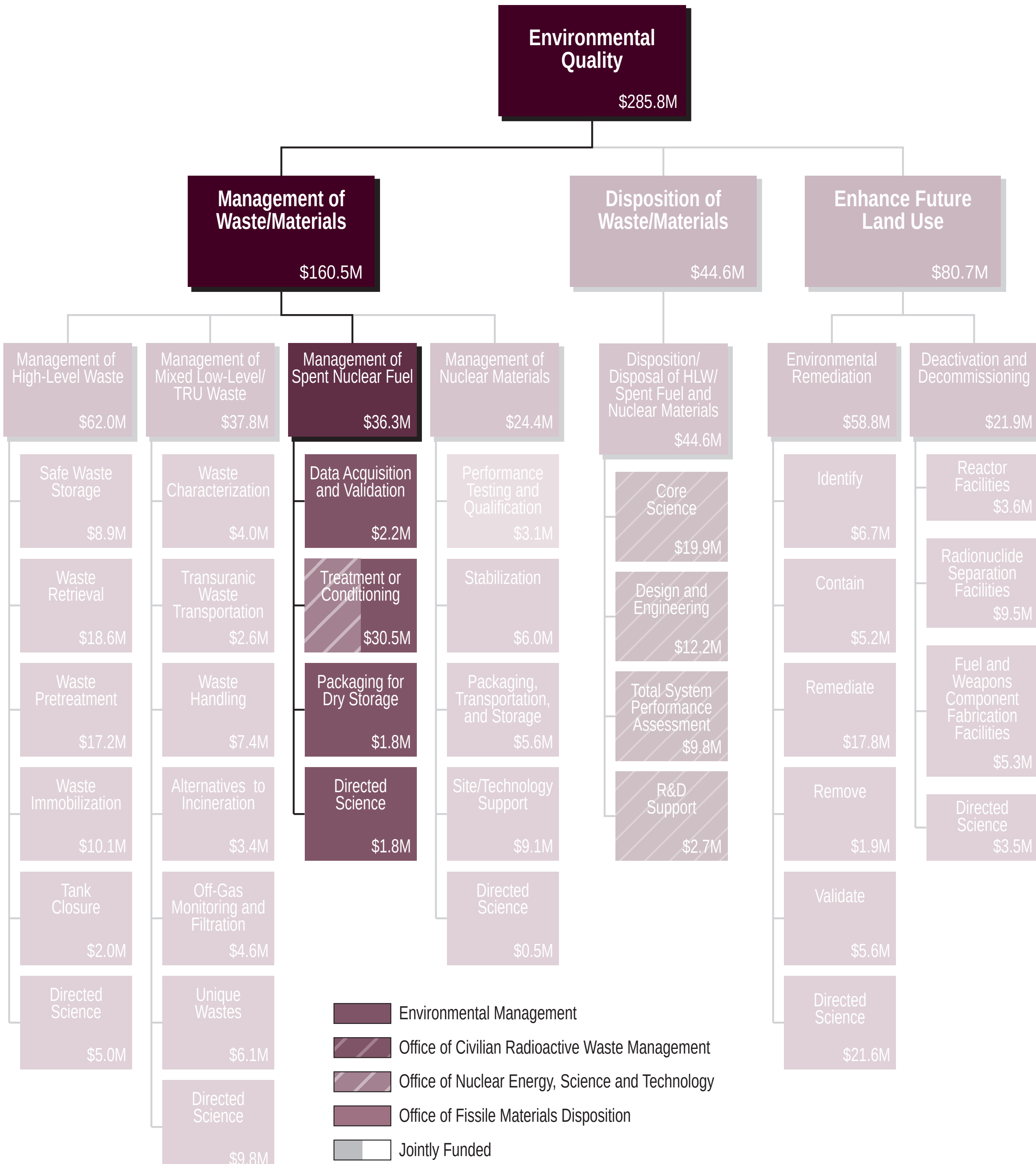
- Computational Simulation. Provides theoretical modeling of structure property relationships that relate to the permeation dynamics of polymer materials. Provides fundamental understanding of the separations processes. Provides thermodynamic and modeling simulations of adsorptive processes in crystal structures.

Budget Summary Table

(Dollars in thousands)

Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Waste Characterization	4,978	5,372	4,004
Transuranic Waste Transportation	1,105	1,663	2,612
Waste Handling	6,049	4,748	7,412
Alternatives to Incineration	3,146	2,438	3,354
Off-Gas Monitoring and Filtration	8,942	7,766	4,568
Mercury Contamination	1,290	0	0
Unique Wastes	2,012	5,443	6,052
Waste Stabilization	565	0	0
Directed Science	9,137	7,535	9,840
Total	**37,224**	**34,965**	**37,842**

Chapter 5
Spent Nuclear Fuel



$ = FY 2001 Budget Request

Chapter 5
Spent Nuclear Fuel

Table of Contents

Page

Overview

Definition of Problem Area

The U.S. operated 14 nuclear reactors between 1944 and 1988 to produce plutonium and tritium for nuclear warheads. In addition, the U.S. operated many other test reactors to encourage and support both commercial and military reactor developments. During that time, most of the nuclear fuel rods and targets irradiated in the reactors were reprocessed to extract the plutonium as well as the leftover enriched uranium for reuse. In addition, the US Navy operated many nuclear propulsion reactors, from which the fuel assemblies were processed to recover and reuse the remaining fissile uranium. These fuel rods, targets, and assemblies are referred to as spent nuclear fuel (SNF). The Department's spent fuel is not categorized as waste, but is highly radioactive and must be stored in special facilities that shield and cool the material. Most spent fuel is stored in indoor pools under water, although some spent fuel is kept in dry storage.

The Idaho National Engineering and Environmental Laboratory (INEEL), the Savannah River Site (SRS), and the Hanford Site generated and now manage most of the existing SNF in the DOE complex. Prior to 1992, most DOE SNF was dispositioned through reprocessing. In 1992, DOE began to phase out reprocessing operations. In 1995, DOE decided upon a planning basis that identified disposal of DOE SNF in the first geologic repository. Since then, deliberations have determined a need to articulate the requirements that must be met in order for DOE SNF to be accepted in the repository. The safe, reliable, and efficient management of DOE SNF and preparation for its final disposition is a major challenge due to the multiple sites involved and the wide variety of SNF types.

In June 1995, a Record of Decision (ROD) was issued for the Programmatic SNF Management Environmental Impact Statement. This ROD, defined the path forward for the management (40-year period) of DOE SNF as regionalization by fuel type. Under this path, as modified by the Idaho Settlement Agreement, SNF management occurs at three primary sites until a geologic repository is opened. The sites are Hanford, INEEL, and SRS. The fuel type distribution is: Hanford fuel will remain at its present location with the exception of its sodium-bonded fuel, which will be transported to the INEEL for treatment; aluminum clad fuel will be consolidated at the SRS; and non-aluminum clad fuels (including the Naval SNF, but excluding the Fort St. Vrain (FSV) SNF, which will be safely maintained at its present location in Colorado) will be transferred or retained at the INEEL.

Hanford Site - Over 2,100 metric tons heavy metal (MTHM) of SNF are currently in inventory. [MTHM refers primarily to uranium metal, but also includes plutonium where present.] 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.

Idaho National Engineering and Environmental Laboratory - Approximately 60 MTHM of SNF will be received from off-site sources. Currently, there are 270 MTHM (640 cubic meters) of SNF in inventory. This quantity includes the 0.8 MTHM in spent graphite fuel located at a dry storage facility in Fort St. Vrain, Colorado managed by the INEEL. After on-site storage, drying, and packaging, all SNF is expected to be shipped off-site to a repository for disposal.

Savannah River Site - Approximately 20 MTHM of SNF are in inventory and 30 MTHM of spent fuel are expected to be received from off-site sources. The spent fuel is expected to be prepared and placed in an off-site geologic repository.

The estimated costs for management and preparation for disposal of DOE's SNF are shown in Figure 5-1.

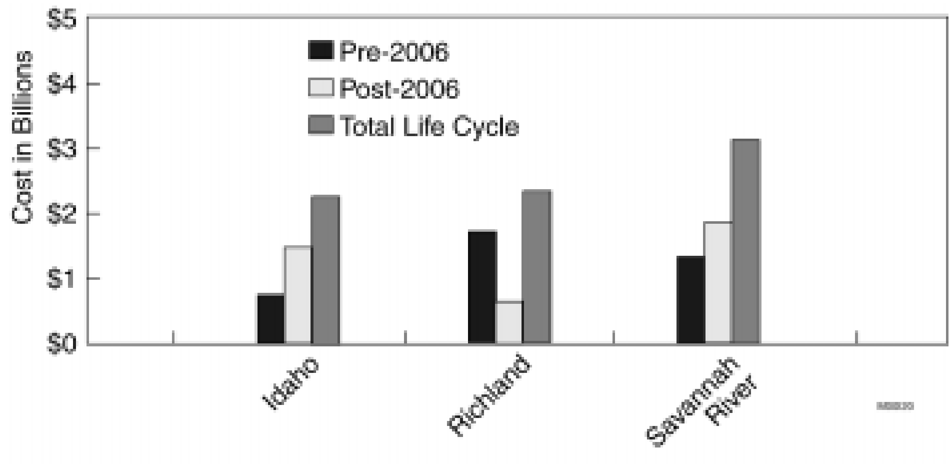


Figure 5-1. Through 2006, Post-2006, and Life Cycle costs for managing spent nuclear fuel.

National Context/Drivers and Federal Role

The Spent Nuclear Fuel investment area generally addresses the need to dispose of the Nation's nuclear legacy, by disposing of a wide range of spent nuclear fuel generated from 1) nuclear power and other commercial and industrial uses, 2) weapons development and nuclear propulsion for national security, and 3) nuclear research and test reactors. End states for DOE spent nuclear fuel include two features: safe and effective interim storage prior to final disposition, followed by shipment of prepared SNF to a Monitored Geologic Repository (MGR). The MGR is scheduled to be opened in 2012, whereupon, DOE SNF shipments will begin, and will continue routinely until completed at about 2035. At the MGR, SNF is to be inserted into waste disposal packages and be placed in geologic strata, while maintaining a retrieval capability for up to 100 years. The Office of Civilian Radioactive Waste Management (OCRWM) will maintain the repository, conduct monitoring, and defer a final decision on repository closure for up to 300 years.

The United States also has growing inventories of spent nuclear fuel from commercial nuclear power reactors, currently stored at reactor sites in 33 states, and spent fuel from nuclear-powered naval vessels. Geologic disposal is the national strategy for the ultimate disposition of spent fuel and of defense high-level radioactive waste. It is also the technical foundation for the international stance on nuclear nonproliferation, as well as the likely path forward for other materials such as excess fissile materials. Figure 5-2 shows the SNF disposition process.

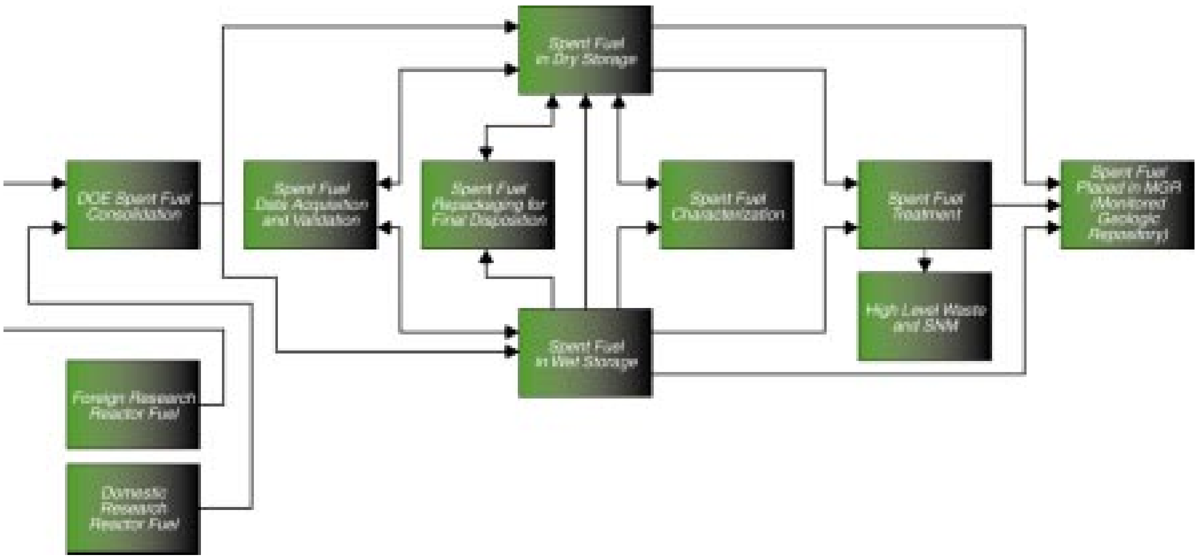


Figure 5-2. Pathway for SNF disposition to a monitored geologic repository.

Linkage to DOE Strategic Goals and Objectives

The spent nuclear fuel activities support and impact the environmental quality strategic objectives at the levels indicated in Figure 5-3.

The primary focus of spent nuclear fuel activities is an Environmental Quality strategic objective, "Dispose or treat spent nuclear fuel in accordance with the Nuclear Waste Policy Act (NWPA) as amended." Two strategies have been outlined to achieve this objective: (1) complete the scientific and technical analyses of the Yucca Mountain site, and if it is determined to be suitable for a geologic repository, obtain a license from the Nuclear Regulatory Commission (NRC); (2) maintain the capability to rapidly respond to potential statutory direction that may include transportation of spent nuclear fuel and high-level waste to a designated interim storage facility.

Each of the SNF projects has particular needs related to the type(s) of fuel and storage configurations at site. The major objectives in each case are to mitigate existing risk sources, establish and maintain safe interim storage conditions, and prepare for final geologic disposition. Positioning the SNF in safe interim dry storage is a primary and immediate objective, well in advance of the MGR.

- Hanford Site: In accord with a tri-party agreement, N-reactor spent fuel will be transferred expeditiously from existing wet-basin storage into a new dry storage facility. The SNF will be stored dry in multicanister over packs (MCO) until MGR shipment.

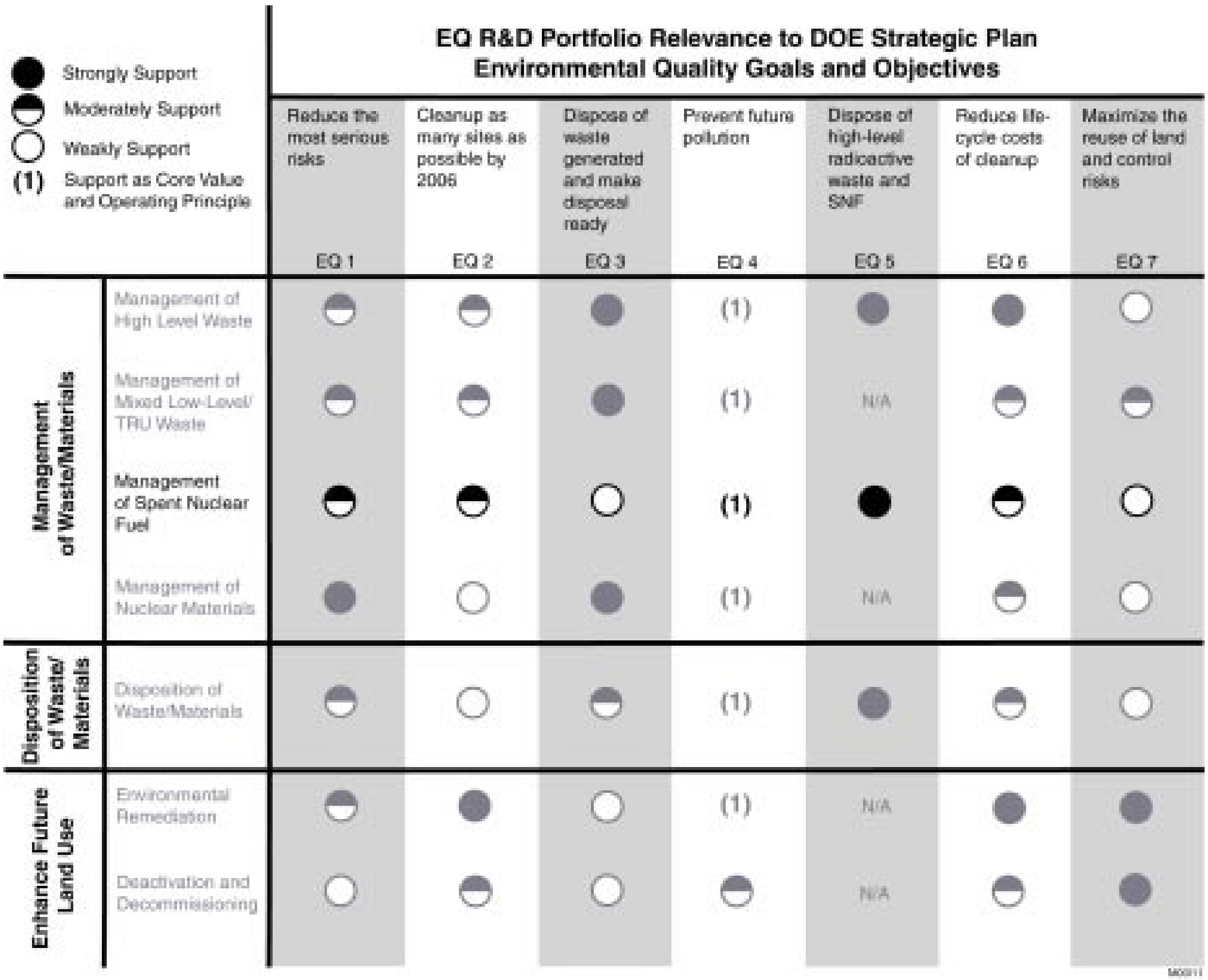


Figure 5-3. Relevance of spent nuclear fuel R&D investments to Environmental Quality goals and objectives.

- INEEL: In accord with a joint agreement with the State of Idaho and the US Navy, INEEL spent nuclear fuel will be transferred from existing wet basins over the next several years, and will be stored in road ready canisters in dry storage facilities awaiting shipment to the MGR, beginning in 2012 and being completed by 2035.

- Savannah River Site: Stored SNF, primarily aluminum based, will be either treated and or dry stored prior to MGR shipments. The preferred path is treatment of the aluminum based SNF to dilute the enriched uranium and to increase the criticality safety, followed by dry storage until MGR shipment.

Problem Area Uncertainties

The Department has made substantial progress in characterizing Yucca Mountain, Nevada, to determine its suitability as a geologic repository site for spent fuel and other long lived wastes. However, DOE continues to face substantial political opposition and legal challenges in implementing its waste disposal mandate under the NWPA, as amended. Waste acceptance criteria for SNF to be shipped to the MGR have been studied at length, but final form is uncertain, and probably cannot occur prior to NRC licensing of the geologic facility. Thus, some potential for change exists, which can then change the direction and magnitude of research and development leading to disposal of DOE SNF. There exist over 250 types of SNF, many of these being unique and one-of-a-kind SNF designs. The obvious differences will require considerable efforts into SNF characterization and repository bounding performance analyses. In addition to identified uncertainties, there remains the continued downward pressure on funding, which increases the uncertainty of a timely and successful conclusion.

R&D Investment Trends and Rationale

Figure 5-4 illustrates the current R&D investments for spent nuclear fuel management.

Figure 5-4. Cumulative investment in spent nuclear fuel areas over 3 years (FY 1999–FY 2001).

In accordance with DOE policy, SNF which meets OCRWM acceptance criteria will be directly disposed into the first geologic repository at Yucca Mountain if it is found suitable as a geologic repository. The few exceptions to this policy are for specific SNF that is at risk during the expected long interim storage period (up to 40 years), and for sodium-bonded fuels. Although the remaining fuel types appear ready for MGR disposition, deliberations within the Department have determined a need to articulate the requirements that must be met in order for DOE SNF to be accepted in the repository. Thus, the technology needs, as identified by the SNF storage sites, span a full range of basic research (e.g., MGR release rates of unique SNF types) to implementation (e.g., nondestructive assay systems to examine SNF cans/canisters).

Although acceptance and transportation of DOE SNF to a MGR is not programmed to begin until 2012 AD at the earliest, significant SNF data and treatment paths are needed much sooner, to ensure safe storage and meet state and DOE settlement agreements, and to support MGR performance studies and licensing activities. Thus, early investment into research and development activities is necessary earlier than at first perceived, based on MGR scheduled availability. This early development is evident in Table 5-1, where development needs are higher in the first five-year period. In addition, development efforts always carry some risk of failure, which may be mitigated either by parallel or sequential alternative development. Evident downward pressures on available funding sources require acceptances of higher risks at earlier stages of development; and if development failure were to occur, as has happened previously, it could result in increased costs as program deadlines draw closer.

Table 5-1. Cumulative investment needs for spent nuclear fuel areas over 5 years and 10 years (dollars in millions).

DOE SNF Site	Five-Year Investment Needs,	Ten-Year Cumulative
ANL-W	35	45
Hanford Site	14	18
INEEL	28	49
Savannah River Site	100	119

Key R&D Accomplishments

The National Spent Nuclear Fuel Program has, in concert with the major SNF storage sites, identified disposal paths and alternatives for nearly all fuel types now in the inventory, and is working on requirements and specifications for DOE SNF disposition in a proposed MGR.

Transportation of many SNF types into improved extended-term dry storage facilities has been initiated.

Acceptance of all EM SNF types into RW MGR licensing and performance analyses has been achieved, with a few exceptions of some having chemical reaction or waste hazards.

The Savannah River site and the INEEL have begun receiving shipments of up to 250 spent nuclear fuel elements from foreign research reactors. The elements, which contain highly enriched uranium of U.S. origin, are being accepted to uphold the Nation's nuclear weapons nonproliferation policy.

Key R&D Issues

The safe management, storage, and geologic disposition of SNF requires solutions to key R&D issues:

- Treatment methodologies for sodium-bonded SNF (Hanford and INEEL) and aluminum-clad SNF (SRS), and others as needed.
- Drying and conditioning processes to allow removal of SNF from basin storage to extended-interim dry storage.
- Safe dry storage of characterized SNF.
- Development of performance models for criticality, heat-transfer, radionuclide source terms, etc., for all fuel types in dry storage and at the repository.
- Determination of degradation rates and corrosion product characteristics for all SNF and treated forms in interim dry storage and the repository.
- Non-destructive assay (NDA) and non-destructive examination (NDE) systems to assist with characterization and certification of SNF, treated forms, and acceptance criteria data (either during or after dry storage).

Problem Area R&D Program

Budget: FY99-$48.5M, FY00-$33.7M, FY01-$36.3M

Program Description

The key technical need areas within the program are SNF data acquisition and validation, packaging for dry storage, and treatment or conditioning (if needed). Directed science research supports these three technical development areas.

Data Acquisition and Validation

Budget: FY99-$1.1M, FY00-$1.6M, FY01-$2.2M

Description, Objectives, and Performers. Data specific to each of over 200 types of DOE SNF is needed prior to certification of the fuel for the MGR. Since many of the DOE SNF types are from one-of-a-kind reactors or reactor fuel experiments and from post-irradiation examinations performed many years ago, the available data quality may not meet the more stringent standards of the present day. For the SNF to be accepted for safe, permanent MGR disposal, fuel data must be certified and qualified prior to SNF shipment from present storage and management sites. Each site will have a significant program for gathering the available data, and for assuring the data's accuracy and qualification.

R&D Challenges. Investments are needed in two areas: one, to determine the necessary pedigree required to "qualify" existing fuel data, and two, in systems for qualifying all data related to DOE SNF types including assembling original manufacturer data and drawings, reactor history, post-irradiation examinations, fissile loading, burnups, storage since reactor withdrawal, fuel quantities, fuel matrix, etc. In order to qualify the SNF data, new systems for NDA/NDE may need to be developed. Development of systems to determine dryness and hydrogen content of SNF packages may also be needed. Methods for determining the integrity of the fuel and storage package will be needed to eliminate the need for repackaging prior to MGR shipment.

R&D Activities: Activities include development of new NDA/NDE systems that can independently verify existing SNF values, e.g., fissile quantities, key radionuclide quantities, and fuel integrity.

Accomplishments:

- Establishment of the National Spent Nuclear Fuel Program fuel database.
- Reports compiled on individual fuel types.
- Reports on capabilities and level of development of existing NDA systems.
- Identification of Multi Detector Array system (MDAS) as a most promising NDA system along with its potential capabilities.
- Reports on characterization requirements for aluminum SNF.

Treatment or Conditioning

Budget: FY99-$44.4M, FY00-$28.1M, FY01-$30.5M

Description, Objectives, and Performers. In some cases the spent fuel may require conditioning or treatment to prepare it for disposal or long-term storage. For example, damaged fuel may need to be conditioned or repackaged to reduce risks. Some fuel types (e.g. sodium-bonded) may contain constituents that are not acceptable at the MGR. Also, spent fuel containing highly enriched uranium may require dilution treatment to avoid potential security and criticality problems during storage or after disposal.

An integrated program is being conducted to develop and evaluate an electrometallurgical treatment technology. This will enable the Department in mid FY-2000 to reach a record of decision on proposed actions to treat EBR-II fuel, and possibly other sodium-bonded fuel, in Idaho. The electrometallurgical treatment technology is a by-product of the unique capabilities developed at Argonne National Laboratory in their support of the Department's Integral Fast Reactor (IFR) and other liquid metal reactor research programs. This treatment technology employs electrorefining techniques to convert spent nuclear fuel into two compact waste forms. This R&D will also help the Department decide on future development of the technology for the treatment of other types of DOE spent fuel. The waste form R&D will provide data to ensure and support ultimate disposition of the electrometallurgical waste forms in a geologically mined repository.

A melt-dilute treatment technology program is focused on the development and implementation of a treatment technology for diluting highly enriched (>20% ^{235}U) aluminum spent nuclear fuel to low enriched levels (<20% ^{235}U) and qualifying the LEU Al-SNF form for geologic repository storage. In order to reduce the enrichment of these assemblies prior to ultimate geologic repository disposal, the melt-dilute technology proposes to melt these SNF assemblies and then dilute with additions of depleted uranium. The benefits accrued from this treatment process include the potential for significant volume reduction, reduced criticality potential, and the potential for enhanced SNF form characteristics. The emphasis within the development program to date has been on determining the process metallurgy and off-gas system design for the treatment of all types of Al SNF (UAl_x, $Al\text{-}U_3O_8$, and $Al\text{-}U_3Si_2$).

R&D Challenges. Investments are needed to complete the development and validation of processes for conditioning/treating specific fuel types, e.g., Na-bonded, small-lot scrap, disrupted fuel, and melt-dilute for aluminum clad SNF.

Disposal of the Experimental Breeder Reactor-II (EBR-II) fuel presents a challenging waste management problem. The presence of the sodium makes this spent fuel unique. Sodium metal is highly reactive; it reacts rapidly in air and will react violently in water. Because the sodium is partially absorbed by the uranium fuel elements, mechanical means may not be fully effective in removing it. Therefore, conservative management assessments indicate this fuel will have to be treated to a waste form acceptable in long-term disposal in a geologic repository. Other DOE spent nuclear fuels may also require treatment prior to long-term disposal.

Disposal of highly enriched Al-SNF in a geologic repository is challenging due to the criticality and proliferation concerns. A dilution treatment process was identified as the most promising alternative.

R&D Activities. Development and implementation of an Al-based SNF melt-dilute process at the SRS. Development and implementation of electrometallurgical treatment of Na-bonded SNF at ANL-W. Development of an epoxy removal technique for metallographic samples from post-irradiation examination of SNF.

Accomplishments:

The technology demonstration at ANL-W applied electrometallurgical technology to the treatment of a limited quantity of EBR-II spent fuel (about 6.25 % of the EBR-II SNF inventory), to help DOE evaluate whether it should be used to convert sodium-bonded metal fuels into durable ceramic and metal waste forms. Electrometallurgical treatment R&D supports the integrated programs to disposition DOE sodium-bonded SNF by providing experimental data, modeling and analyses needed for full process integration, and resolution of technical challenges expected during the transition to treatment operations. These R&D activities are also being used to help the Department reach a record of decision on proposed actions to treat EBR-II fuel, and possibly other sodium-bonded SNF.

- Issued the Draft Environmental Impact Statement for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel in July, 1999.
- Successfully met or exceeded during 1999, all four key electrometallurgical treatment technology demonstration criteria – treatment throughput rate, product stream quantification, process reliability, and nuclear material accountancy and regulatory compliance.
- Issue in 2000 the Record of Decision and Final Environmental Impact Statement for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel on the future use of electrometallurgical treatment.
- Continue R&D activities to support high-throughput treatment of sodium-bonded SNF, including optimization of operating parameters, and process and model development to improve equipment operation, integration and reliability.
- Continued waste form durability testing, performance assessment modeling, and repository qualification plan development.
- Conduct long-term tests to characterize performance and support license applications and regulatory acceptance of reference waste forms.

Definition of the technical bases for the Melt-Dilute Treatment Technology at the SRS was achieved through several technical activities:

- Demonstrate the versatility of technology to treat the major types of Al-bases DOE SNF-UAL_X, U_3Si_2, and U_3O_8.
- Define the optimum treatment cycle and basis to include melt time, melt temperature, alloy, composition, batch size, casting technique, furnace type, and atmosphere conditions.
- Develop the fundamental requirements for the treatment technology off-gas system by defining absorber bed materials, flow rates, volatile radionuclides, radionuclide release fractions, and disposition options for off-gas secondary wastes.
- Identify pre- and post-treatment materials characterization strategies to satisfy DOE-RW Draft Waste Acceptance Criteria.
- Develop a full-scale (1 MTR Batch Size) Melting Apparatus for treatment technology and off-gas system development.
- Develop an MD integrated process with depleted uranium surrogate fuels.

Treatment and conditioning of INEEL SNF was advanced through epoxy studies and drying tests.

- Performed prototype testing of thermal process for epoxy treatment.
- Completed a campaign of vacuum drying aluminum-plate and uranium-zirconium-hydrate fuel as removed from wet basin storage.
- Completed initial tests and first drying cycle using an elevated temperature vacuum process on canisters containing TMI-2 debris.

Packaging for Dry Storage

Budget: FY99-$0.9M, FY00-$1.7M, FY01-$1.8M

Description, Objectives, and Performers: Extended, interim, dry storage of SNF is the preferred path for safe management of DOE SNF until shipment to the MGR. At present, most SNF is or has been stored in water basins. In some of these basins, measurable corrosion of the SNF has occurred. Movement of all SNF into dry storage will limit or eliminate potential corrosion mechanisms. For some SNF, repackaging will be needed to ensure containment during the extended storage period. Since the SNF may be in storage for periods up to 30 years or more, assurance must be made the SNF will be manageable prior to MGR disposition.

Because spent nuclear fuel varies appreciably in type, quantity, form, radioactivity and condition, the fuels must be characterized before they are disposed of in the repository. Data needs are being developed by affected DOE organizations for the characterization of more than 250 types of DOE spent fuel. (Because of its classified nature, the Navy will characterize its own spent fuel, and will provide DOE with their analyses). Due to age, degradation, or specific type, some DOE spent fuels may require conditioning or stabilization before they can be accepted for disposal. A determination of the appropriate "data needs" for these conditioned/treated forms is necessary. Use of a consensus code approved test method or test protocol would be beneficial.

R&D Challenges. Investments are needed to determine packaging requirements to ensure safe dry storage for periods up to 40 years. Packaging must maintain adequate SNF integrity, prevent undue corrosion, and be able to be adequately monitored throughout the dry storage period. It also would ensure that at the end of the extended interim storage the SNF and canister would meet the MGR Disposability Interface Specifications. Focus also is on activities related to retired basin storage facilities.

Investments are needed to identify monitoring needs, design and implement monitoring stations, and for new systems to detect and measure SNF changes during the extended storage period. Investments are needed to ensure that SNF data may be qualified and verified prior to shipping to the MGR.

R&D Activities:

- Examination and measurement of all degradation, including pitting, microbiological induced corrosion in water basins, etc.
- Testing of Al-based SNF in experimental instrumented dry-storage test devices.
- Detecting moisture remaining within a complex geometry fuel element.
- Drying physically entrained water in SNF.
- Programming computer codes for optimal loading of dual-purpose canisters.
- Mechanically drying carbon/graphite SNF.
- Removing epoxy materials before placement into dry storage.
- Inserting metal corrosion coupons into dry storage systems.
- Examining basin stored SNF for degradation e.g. pitting, micro-biologically induced corrosion etc.
- Detecting and mitigating microbiologically induced corrosion in SNF dry storage containers.
- Detecting interactions between SNF and storage containers.
- Inserting Representative Treated SNF Form Coupons in dry storage systems.
- Defining and acquiring appropriate instruments and sensors for SNF performance monitoring.

- Developing instrumented test canister system for monitoring of long term performance.

Experiments have been designed to simulate long-term, environment-specific performance of spent fuel and high-level waste glasses. Test methods and test protocols are being processed through American Society for Testing and Materials (ASTM) committees to facilitate establishment of consensus standards for SNF and high-level waste glass. A second focus is on NDA/NDE systems and techniques for fissile and radioisotopes, for detecting water (bound or free) in SNF canisters, and for ensuring continuing fuel-handling capabilities. Burn-up meters and uranium isotopic analytical systems are being developed for aluminum SNF.

Accomplishments:

- A detailed, preliminary design of a standardized canister (18” or 24” Dai.) has been completed. The canister is designed for 50 psig and drop heights up to 10 meters for stored SNF.
- Corrosion data in dry (and humid) storage environments have been developed for aluminum SNF.
- The storage criteria (acceptance criteria) have been developed for aluminum SNF defining the window of temperature, humidity and drying condition.
- Drying systems have been demonstrated and used at three major sites managing and storing SNF.
- Systems for detecting water in canned SNF have been demonstrated.
- Drying tests have been performed on a variety of simulated SNF including Al based fuels.
- Instrumentation required for monitoring SNF performance has been developed and incorporated into test packages.
- Thermal models for aluminum SNF in interim dry storage packages have been developed.
- Criticality models for aluminum SNF in interim dry storage have been developed.
- Performed placement of stainless steel coupons with basin corrosion products into dry storage conditions for monitoring potential for continued corrosion.
- An experimental instrumented test canister has been developed and long-term dry storage of aluminum SNF in the instrumented test canister is under way.
- The performance of aluminum SNF in dry storage (both corroded and non-corroded) SNF are being monitored in the instrumented test canister.

- An NDE magnetic resonance imaging system for measuring water content is being evaluated.

Directed Science

Budget: FY99-$2.1M, FY00-$2.4M, FY01-$1.8M

The Department funds research that advances science to solve environmental problems associated with safely and efficiently managing spent nuclear fuel from both domestic and foreign reactors. Six subcategories of needs were identified in the area of spent nuclear fuel:

- Stabilization of spent nuclear fuel, including mechanisms of pyrophoricity and combustion parameters for various fuel types.
- Characterization/nondestructive examination (moisture content, radioisotope inventory, physical condition, criticality, and synergistic effects) of spent nuclear fuel.
- Characterization corrosion, degradation, and radionuclide release mechanisms, kinetics, and rates for the representative fuel matrices; mechanisms which may lead to accelerated degradation of containers; dissolution characteristics of the matrices; and the effects of microbes on fuel packages; long-term storage and deterioration of fuel/canisters of spent nuclear fuel.
- Characterization of water clarity of basins.
- Development of alternative spent nuclear fuel processes; waste forms; alternative disposal process; mixed oxide fuels.
- Development of methods to remove moisture without damage to the fuel elements.

The spent fuel directed research portfolio is concentrated in the scientific areas of analytical chemistry and instrumentation, engineering science, geochemistry, separations chemistry, materials dynamics and computational simulation.

- *Analytical Chemistry and Instrumentation.* Development of detectors for direct imaging of spent nuclear fuels and fissile materials, applying high-resolution gamma-ray imaging technologies to environmental remediation of radioactive hazards, investigating fabrication of field-usable detectors, and demonstrating the performance of such a system using a small configuration of detectors.
- *Engineering Science.* Developing techniques to model fluid flow in spent nuclear fuel canisters. The primary goals are to a) develop a method to visualize flow in the presence of a reacting surface, b) use the Matched-Index-of-Refraction facility at the INEEL in conjunction with laser doppler velocimetry to measure flow field velocities within a spent fuel canister, and c) develop a computer model of the flow field and use the experimental results to validate the code.
- *Geochemistry.* Long-term assessment of radionuclide immobilization in the phases formed by corrosion of spent nuclear fuel and immobilization of radionuclides in the

alteration phases of spent fuel. This requires a careful analysis of direct disposal of spent nuclear fuel or of mixed oxide fuel (fabricated for the disposal of excess weapons plutonium).

- *Separations Chemistry*. Specific research is being conducted in the area of catalyst chemistry and waste treatment. This task will study the radiolytic reactions, "drying" processes, and corrosion behavior of actual SNF materials. A model will be developed and tested against actual fuel rod behavior to insure validity and applicability to the problems associated with developing dry storage strategies for DOE-owned SNF.

- *Materials Dynamics.* Characterization, predictions, and mitigation of changes in the microstructure and properties of materials over very long periods of time. Three particular topics with the general area of dynamic behavior of materials are of particular concern:

  (a) *Transport in Solid and Liquid Media.* There is a need to determine the effective macroscopic transport properties of an inhomogeneous media from its microstructural morphology. The research includes (1) development of methods to quantitatively characterize complex microstructures, and (2) development of analytical and computational models to calculate effective transport properties from the microstructure characterization and the equations of motion for the phenomena of interest. The transport properties of particular interest are thermal and electrical conductivity, fluid permeability, and diffusion of molecular species. Both static and dynamic (non-equilibrium) microstructures are considered. Phenomena to which this work may be applied include leaching from waste forms, molecular diffusion through storage containers, trapping of contaminants at surfaces in porous media, vitrification by resistance heating, and production of thermal gradients by chemical and nuclear reactions in stored waste.

  (b) *Corrosion and Aging.* There is a lack of fundamental information on the role of microbiological activity in spent nuclear fuel storage basins and on spent nuclear fuel surfaces. Focus will be on examining the attachment of microorganisms on aluminum alloys, stainless steels, and zircalloy and to develop an understanding of the deterioration of the passivation layer on the substrate, which leads to localized corrosion beneath the biofilm. A particular focus will be to examine the biocorrosion of weldments that are thought to be localized areas of chemical inhomogeneity compared to wrought parent materials.

  (c) *Coatings for Environmental Applications.* Despite the successful use of coatings in some engineering applications there is very limited scientific understanding of either the coating process or the resulting materials properties. Aspects of spray coating processes will be examined in order to determine the relationship between particle size, velocity, and temperature as well as the coating microstructure and mechanical properties. The role of process variations and surface preparation methods on residual stress and bonding will be examined using finite element numerical simulations and experimental measurements to better understand bonding between coatings and substrates, particularly oxidized or corroded materials.

- *Computational Simulation of Mechanical and Chemical Systems:* Delivery of computational modeling capability and results for chemical and physical processes that occur in the wide range of systems of importance to DOE EM.

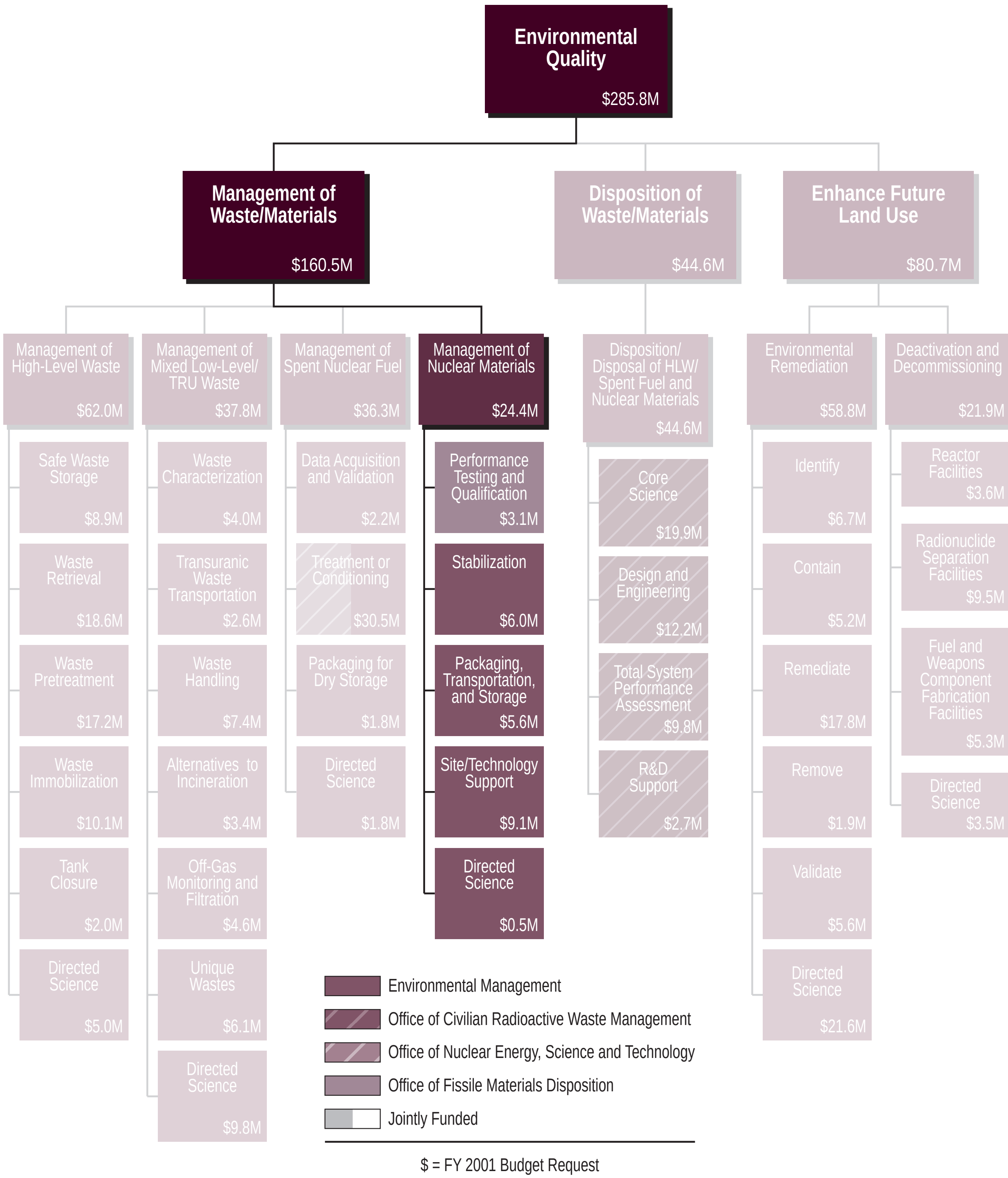
  (a) Computational Simulation. Computations to support the understanding of fracture propagation in materials and the interfacial properties of coatings and their substrates that relate to coating performance.

Budget Summary Table

(Dollars in thousands)

Program Activity	FY 1999 Appropriation	FY 2000 Request	FY 2001 DOE Request
Data Acquisition and Validation	1,080	1,600	2,220
Treatment or Conditioning	44,391	28,100	30,484
Packaging for Dry Storage	900	1,690	1,780
Directed Science	2,101	2,350	1,835
Total	**48,472**	**33,740**	**36,319**

Chapter 6
Nuclear Materials



Chapter 6

Nuclear Materials

Table of Contents

Overview

Definition of Problem Area

A primary mission of the Department of Energy (DOE) and its predecessors has been the national security of the United States. Since the Manhattan Project, the DOE and its predecessors have produced special nuclear materials and manufactured nuclear weapons. This historical emphasis underwent a significant change beginning in 1989. The Cold War ended and the START series of treaties dramatically decreased the needed inventory of nuclear weapons. As a consequence, considerable quantities of nuclear materials that had previously been deployed around the world as nuclear weapons components were returned to the Department. The reduced threat to the nation and the treaties into which the nation entered caused a large portion of these materials to become surplus to needs for the national defense, and DOE initiated a major program to disposition these materials in a way that would be non-proliferant. Also, the significant reduction in the nuclear weapons stockpile, and the corresponding reduction in requisite weapons production capacity, presented DOE with an opportunity to downsize its weapons complex and to close a number of facilities and sites.

Approximately 200 metric tons of U.S. weapons usable fissile materials have been determined to be surplus. The DOE Office of Fissile Materials Disposition (MD) is responsible for the disposition of this material, which will be accomplished either by burning the material in electricity-producing commercial reactors to produce spent fuel, or immobilizing the material with high-level waste for disposal. All EM weapons-usable materials not disposed of as waste will be transferred to MD at a point in time yet to be determined. The buildings currently housing this material cannot be decommissioned while the materials are present. Hence, the removal of the materials is on the critical path for closure of facilities and sites such as Mound and Rocky Flats.

Growing concerns about safety and environmental problems caused the Department to temporarily suspend various operations throughout the weapons complex in the late 1980s and early 1990s. Many of these shutdowns became permanent with the end of the Cold War and the collapse of the Soviet Union. However, because the shutdowns were viewed as temporary at the time, the Department did not make long-term storage or disposition plans for surplus materials prior to suspending operations. For the same reason, the halt in weapons production that began in 1989 “froze” the manufacturing pipeline, leaving it in a state that posed significant risks. These risks were identified in three vulnerability assessments (spent nuclear fuel, plutonium, and highly enriched uranium) undertaken by DOE and in DNFSB Recommendations 94-1, 97-1 and 2000-1, dealing with high risk forms of special nuclear material. Subsequently, DOE has established implementation plans to eliminate or reduce these risks. Also, DOE has entered into a variety of stakeholder agreements governing on-site inventories of radioactive materials, schedules for facility and site closure and related matters.

Another material of concern to the Department is depleted uranium hexafluoride. Comprising over 700,000 metric tons, this inventory is the focus of a program to convert the material to a more stable form. The program’s research and development activities are focused on development of beneficial uses and assuring paths to disposal, as required. Detailed information concerning this program's research activities will be provided in the next revision of this portfolio.

The estimated costs for management and disposition of DOE's nuclear materials are shown in Figure 6-1.

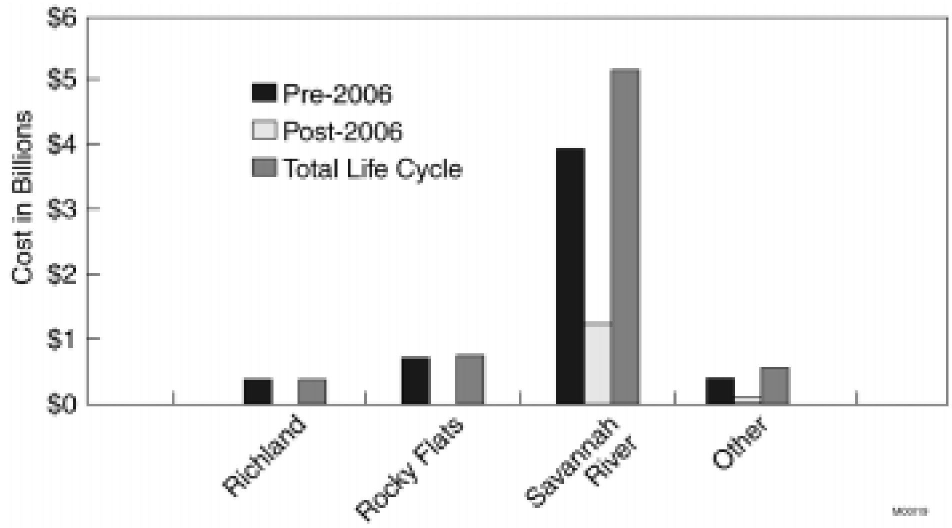


Figure 6-1. Through 2006, Post-2006, and Life Cycle costs for managing nuclear materials.

National Context/Drivers and Federal Role

The nuclear material inventories around the country are viewed as a safety and environmental problem. The safety issues have been identified in various DOE assessments and DNFSB recommendations. The safety issues arise primarily from the relatively unstable form in which the nuclear materials have been kept. Stabilization of these materials is required for safe storage. It is also required before inventories can be removed from buildings to be decommissioned and, ultimately, transferred from the sites.

Further, U.S. surplus inventories have been offered for International Atomic Energy Agency (IAEA) safeguards. Some surplus materials at RFETS and Hanford are already under IAEA Safeguards. Stabilization of much of the surplus inventory is required to put them in a form that allows such safeguards to be put in place.

The United States has determined that excess weapons-usable fissile materials in the U.S. and in Russia pose a threat to national and international security due to the potential for global proliferation. Conversion of these materials to a form that makes them difficult to divert and/or use in nuclear weapons is essential for reducing these risks. The U.S. and Russia are currently negotiating disposition agreements.

Linkage to DOE Strategic Goals and Objectives

Nuclear materials R&D initiatives strongly support several DOE Strategic Plan Environmental Quality Goals and Objectives, as shown in Figure 6-2. Stabilization of the various forms of material into forms suitable for storage supports EQ1 (Reduce the most serious risks). It is also essential for accomplishing the removal of nuclear materials from RFETS, which is on the critical path for site closure (EQ2 - Clean up as many sites as possible by 2006), as well as EQ3 (dispose of waste generated and make disposal ready). The R&D also has a role in reducing life-cycle costs of cleanup (EQ6), because delays in addressing nuclear materials requirements will delay cleanup activities.

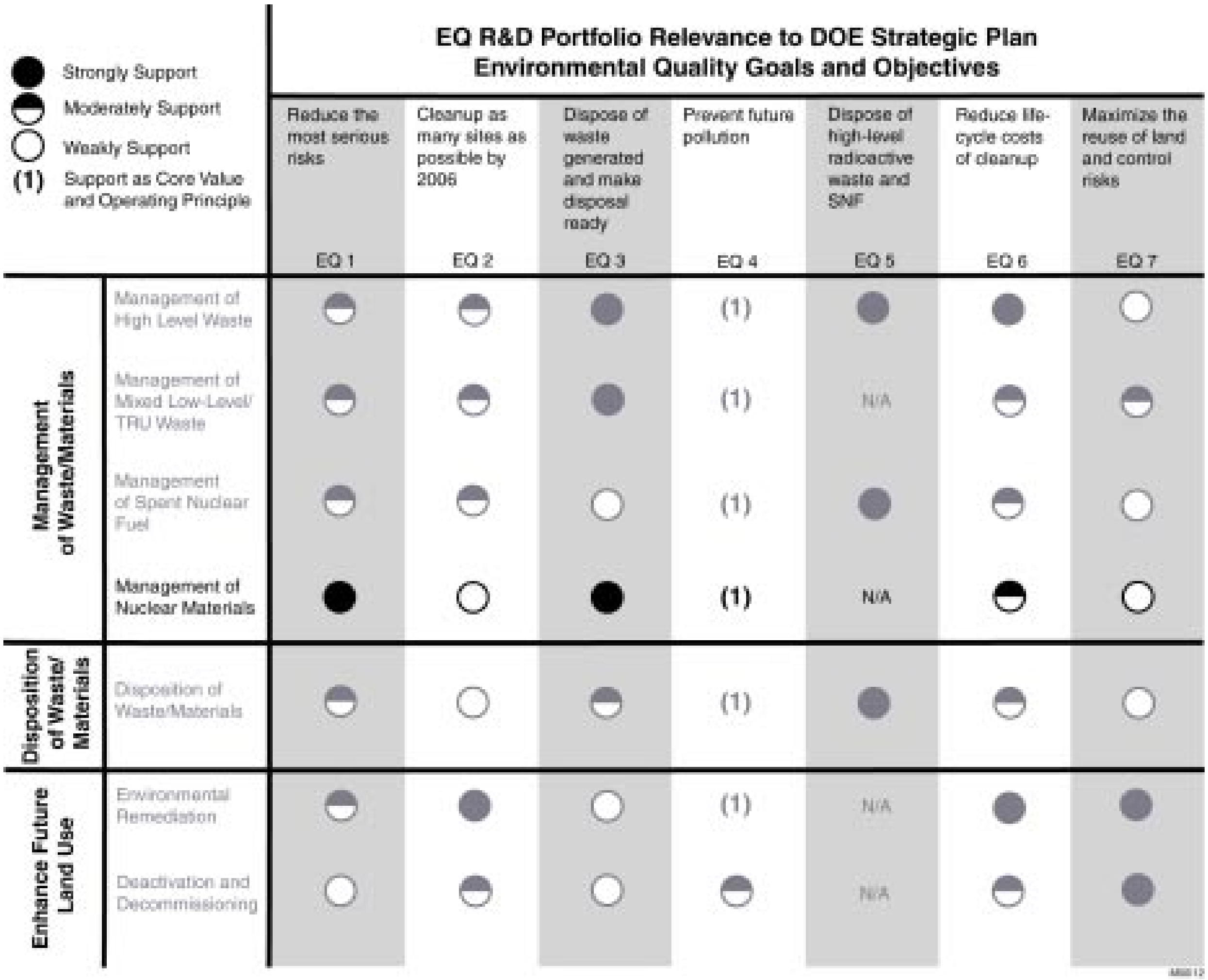


Figure 6-2. Relevance of nuclear materials R&D investments to Environmental Quality goals and objectives.

Problem Area Uncertainties

A significant uncertainty in this Problem Area is the limited knowledge of the specific characteristics of the items that comprise the nuclear material inventory. There has been some characterization of higher-risk items around the complex; however, many items will never be completely characterized. Historical databases have detailed information on nuclear material content, but little information on other constituents in the items. This imposes uncertainties in how these items need to be treated to achieve a stable product that can safely be stored for up to 50 years.

Another area of uncertainty results from the complex, interconnected strategies and plans for managing materials at DOE sites. Changes in plans, or unanticipated events at one site, with other DOE programs or in transportation can seriously impact requirements at another site, requiring changes in technical approaches for dealing with these materials. This requires Nuclear Materials R&D personnel to be acutely aware of the coordination of national strategies.

R&D Investment Trends and Rationale

Figure 6-3 illustrates the current R&D investments for nuclear materials management.

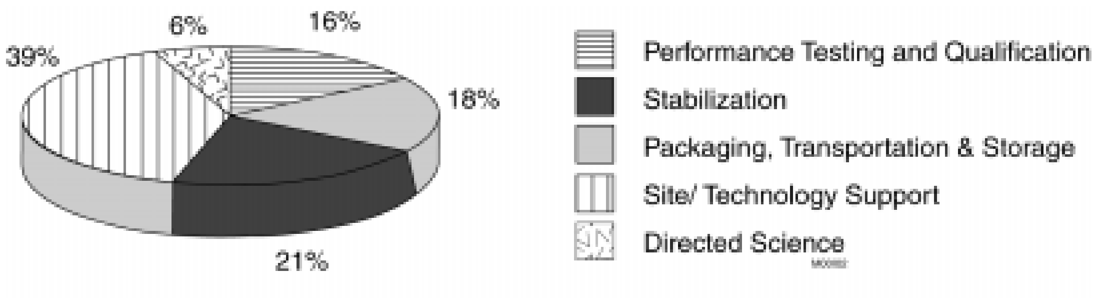


Figure 6-3. Cumulative investment in nuclear materials areas over 3 years (FY 1999–FY 2001).

Trends in technology development funding follow generally the perceived needs, confirming that funds are being spent on the most important issues. To date, stabilization has been a major element for the program. However, that funding is projected to decrease over the next few years as materials are stabilized, or as low risk disposition paths are identified. Site technology support will become more important, reflecting the increased concern over storage, surveillance, and removal of radioactive sources from the closure sites.

Key R&D Accomplishments

Key accomplishments have involved developing stabilization technologies, characterizing materials, expanding the technology base for safe storage, and developing surveillance and monitoring approaches. Specific accomplishments are outlined below:

- Developed technologies for the stabilization of plutonium pyrochemical salt process residues.
- Developed technologies for combustible residue stabilization.
- Developed vitrification techniques for ash, graphite, and sand, slag & crucible residues.
- Characterized and stabilized representative Rocky Flats and Hanford plutonium items.
- Developed moisture measurement methods to certify material stability after processing.

- Solidified the technical basis for storage of impure plutonium oxides.

Key R&D Issues

The most important R&D issues are ensuring that the efforts are as relevant as possible to evolving site needs, requirements, and constraints, and that R&D priorities adequately reflect site schedule drivers. The strategy for developing technology is to identify needs, solicit technology alternatives, recommend acceptable technology choices and monitor performance and progress. Programmatic risk assessments of baseline and competitive alternative technologies based on technical maturity and need date provide the basic elements for prioritization.

Problem Area R&D Program

Budget: FY99-$25.3M, FY00-$22.2M, FY01-$24.4M

Program Description

The scope of DOE activities includes surplus plutonium materials, special isotopes, and other fissile materials. DOE is working on solutions to site-specific and complex-wide technology issues associated with nuclear material risk reduction, stabilization, and preparation for disposition to:

- Expedite complex-wide progress toward cleanup and site closure.
- Standardize resolutions, practices, and equipment systems.
- Promote integration to meet established requirements.
- Produce more cost-effective programmatic results.

Currently, the EM technology development projects are derived in the Nuclear Materials Focus Area FY2000-FY2004 Multi-Year Program Plan, November 1999, DOE/ID-10728, and the technology needs identified by field offices. This plan identifies gaps in technology that may pose significant worker and public safety risk and/or programmatic risk to timely nuclear materials disposition and, hence, site closure. This program plan recommends projects intended to enhance and expand existing scientific data to handle, process, store, and safely disposition nuclear materials by resolving gaps in existing technology. Most of the focus in the past has been on plutonium. That approach is being broadened to systematically evaluate disposition paths of other nuclear materials as well. The nuclear material program also provides technical support to field offices, develops and maintains core competencies, and provides technical support for short-term critical issues associated with site de-inventory, cleanup and shutdown.

Performance Testing and Qualification for Repository Disposal

Budget: FY99-$4.4M, FY00-$4.2M, FY01-$3.1M

Description. The Department plans to disposition surplus weapons-usable plutonium by transforming this material to forms not readily accessible for use in nuclear weapons, i.e., the spent fuel standard. Two forms are under consideration: the mixed-oxide spent fuel and an immobilized plutonium form encapsulated in high-level waste canisters. To support current Departmental plans to dispose of these forms in a federal geologic repository, two distinct and parallel efforts are underway: Performance Testing and Form Qualification. The Performance testing effort is designed to support analyses for the Repository License Application. The purpose of the Form Qualification effort is to demonstrate that the plutonium forms meet deep geologic disposal requirements. Lawrence Livermore National Laboratory is responsible for providing thermochemical and physical property data, and a long-term dissolution model of the ceramic form. Argonne National Laboratory is responsible for conducting both short-term and long-term tests to study the dynamic behavior of the ceramic material. Pacific Northwest National Laboratory is responsible for examining the effects of radiation damage on the physical and chemical properties of the ceramic form and for providing thermochemical data on various complex chemical systems.

R&D Challenges:

The R&D effort establishes tests required to support the development of models that completely characterize the behavior of a new high-performance ceramic form containing plutonium under the potentially challenging environment of a geologic repository. These tests are difficult to perform because most of the elements of concern are below measurement detection limits. Another technical challenge is the development of a long-term dissolution model that can adequately predict the dissolution rate of the ceramic form in such a complex environment as that of the repository, coupled with the many uncertainties that exist regarding unanticipated future events. Other challenges also include the lack of important thermochemical data associated with key chemical elements that are unique to the plutonium form. Significant data gaps identified in the solubility database of materials will need to be filled in. These specifically relate to the likelihood of solid phases forming in repository water chemistries that have not been previously observed or characterized.

R&D Activities:

A series of short-term (a few days) and long-term (years) dissolution tests designed to characterize the degradation behavior of the high-performance ceramic forms are being conducted. Short-term tests are designed to provide an estimate of the forward dissolution rate and serve as a comparative test between samples. Long-term tests are designed to characterize the corrosion behavior of the ceramic form. These tests will also provide information on the interactive effects of the ceramic with the high-level radioactive borosilicate glass, colloids formation, and the effects of temperature and pH on the dissolution rate. Radiation damage due to alpha decay of plutonium is also being studied. Test results will then be used to synthesize a consistent model to identify the rate-limiting process. These data will also be used to support criticality analyses, and performance assessments of the geologic repository.

In addition to the short-term and long-term dissolution tests, a number of other tests are also being conducted to obtain thermochemical data of different phases comprising the ceramic formulation, and other complex chemical systems, including gadolinium, hafnium, uranium phosphates, plutonium phosphates, and titanium oxide.

To demonstrate that the plutonium form qualifies for the repository, the Form Qualification effort will develop the acceptance specifications for the plutonium product, show how compliance with these specifications will be met, and demonstrate compliance through tests. A significant effort in the qualification process will be the development of the Product Control Model. This Model will quantitatively relate the mineralogical composition of the form as a function of input composition and processing conditions.

Accomplishments:

- Completed Ion Irradiation Study.

- Completed Fabrication of Pu238 doped ceramic for radiation damage study.
- Completed report on solubility of titanium dioxide
- Completed report on Pu phosphate solubility.

Stabilization Process Development

Budget: FY99-$5.2M, FY00-$4.1M, FY01-$6.0M

Description. Stabilization to rather stringent specifications is required for plutonium and other nuclear materials that are to be placed in long term storage. It is also often required prior to shipment to other sites. Residues generally need not meet such stringent stabilization criteria, but still must be stabilized to the extent that they may be safely dispositioned either for fissile material recovery, or may be emplaced in a waste repository (i.e., they must meet the repository waste acceptance criteria).

The term "stabilization" can also include any mechanism that will effect a change in the character of the materials being processed. This includes conversion of weapons components to unclassified forms, removal of surface plutonium contamination, separation of elements (such as plutonium and uranium), conversion (such as conversion from a metal to an oxide), and various aqueous and pyrochemical processes that may be used to handle materials such as radioactive sources and high fissile content residues. The research efforts associated with this "expansive" interpretation span a wide variety of technologies but are all directed at placing materials into a form that will support satisfying closure site requirements.

This work package includes international coordination initiatives that are primarily concerned with identification, development, demonstration and deployment of promising technologies that have application in foreign countries, particularly the Former Soviet Union. Of special interest nuclear materials R&D are techniques for stabilizing problematic actinide residues and waste solutions. Russian collaborative research projects are funded by the U.S./Russian Joint Coordination Committee for Environmental Management (JCCEM). Current coordination efforts involve the development of a Russian technology that provides an alternative to the vitrification process for stabilizing problematic liquid waste. The final waste form is a stable ceramic material, suitable for safe transportation and treatment or long-term storage. Verification testing, first with surrogate materials and finally with solutions in inventory, will provide the basis for processing, cost and schedule comparisons.

R&D Challenges:

The major challenge in the area of stabilization is the lack of specific knowledge about the non-SNM constituents of the materials to be stabilized. This lack of knowledge imposes a requirement for stabilization processes that are forgiving of a wide range of constituents. A second challenge is the fact that site baselines change with time, causing R&D needs to change accordingly. In some cases complete disposition paths either have not been identified, or the paths selected continue to have significant technical risk. In many cases the development of alternatives to the traditional methods of material processing is required due to facility closure or by stakeholder agreements. In any case, R&D must be applied to facilitate selection of a disposition path and to minimize the risk associated with the paths selected.

R&D Activities:

Actinide Solution Stabilization Technologies: Liquid actinide solutions have posed some of the most serious risks. Techniques for precipitation of plutonium solutions largely have been developed and implemented. Technologies for vitrification of americium and curium in solutions are currently being developed.

Plutonium Residue Stabilization Technologies : Stabilization technology development efforts have been initiated for treating pyrochemical salt residues, ash residues, graphite fines, crucibles, combustibles, and fluorides. Several approaches were suspended based on trade study recommendations and determination that some materials could be directly discarded. Some other approaches are entering a deployment phase. R&D efforts are being brought to conclusion for the majority of the residue inventories. There will likely be additional technology needs established as the remainder of the residue inventories are evaluated and characterized.

Characterization of PFP, RFETS, SRS, LLNL, and LANL Materials: Lack of chemistry and physical characterization of site materials limits the identification of effective stabilization processes and the understanding of the performance of each item in a storage container after stabilization and packaging. Characterization and stabilization parameters investigation for materials from each of the sites continues.

U-233 Stabilization Technologies: The execution of DOE's Implementation Plan for DNFSB Recommendation 97-1, "Safe Storage of Uranium-233," has accelerated the inspection, chemical stabilization, and repackaging of selected 233U materials.

Aqueous Processing: In the area of aqueous processing, research will address the special problems of processing certain Rocky Flats residues in the Savannah River canyons as well as alternatives to canyon processing to separate uranium from plutonium.

Decontamination: Technology will be developed to remove plutonium surface contamination, primarily from uranium parts, so that the uranium can be reused by other programs.

Declassification: Other research will develop technologies to remove the classified characteristics of components remaining at the Rocky Flats within the operational constraints of the site

Accomplishments:

Salt Oxidation: Salt oxidation has been developed and deployed at RFETS. The process oxidizes constituents that could exhibit pyrophoric behavior and generate hydrogen in storage.

Salt Distillation: Partway through development, it was determined that a separation step was not necessary for disposal of RFETS salt residues. However, the technology is being deployed at Los Alamos for recycling salt in ongoing pyrochemical operations, thereby eliminating a significant waste stream.

Vitrification: This approach was tested for treatment of sand, slag, and crucible residues, graphite fines, and incinerator ash. The primary application was suspended because these items could be discarded to WIPP without further treatment. However, vitrification is being deployed at LANL as a replacement for cementation in waste operations in order to increase the loading of waste containers.

Phosphate Bonded Ceramics: Chemically-Bonded Phosphate Ceramics have been demonstrated as a highly stable, leach-resistant means of immobilizing Pu-bearing ash and ash heel. This technology is also expected to prove useful for many other DOE complex wastes.

Polycube Pyrolysis: Pyrolysis uses a high-temperature inert environment to break down and volatilize polymeric materials. A pyrolysis furnace and off-gas treatment apparatus have been successfully demonstrated Deployment at Hanford is being deferred while approaches that use existing Hanford equipment are being evaluated. A pyrolysis unit is being deployed at LANL to treat combustible materials.

Characterization of PFP, RFETS and LANL Oxides: Pre- and post-stabilization samples of materials expected to be packaged for long-term storage have been characterized to verify the efficacy of the stabilization process. Additional materials from RFETS and SRS are being sent to LANL for evaluation.

RFETS Residue Stabilization: Process development is complete in the Borax/PuF_4 shake test, the CCL_4/HCl uptake on granulated activated carbon, aqueous fluoride precipitation, and fluoride cementation.

Electrolytic Decontamination: Developed and implemented electrolytic decontamination of gloveboxes, nuclear materials containers and HEU at Rocky Flats and Richland.

Packaging, Transportation and Storage

Budget: FY99-$4.0M, FY00-$3.1M, FY01-$5.6M

Description. The primary activities in packaging and transportation are developing the technology base for DOE storage standards and resolving shipping container certification issues. The most pressing current issue in packaging, transportation and storage of nuclear materials is bounding the generation of gas, particularly hydrogen gas, within the nuclear materials package. The gas generation rate must be estimated to properly assess safety issues during transportation and storage. Alternatively, some means must be found to mitigate the effects of gas generation. In the future, ALARA-based techniques, such as glovebox automation technologies and new systems for repackaging nuclear materials may become a part of this work scope.

Long term safe storage of nuclear materials is an essential element of the Department's nuclear material management strategy. Long-term storage is differentiated from shorter term storage by the length of time the material is in storage (typically, up to 50 years or longer) and by the desire to minimize personnel exposure from surveillance during the storage period. LANL and SRS are collaborating to develop an integrated surveillance plan to identify the activities to monitor a statistical sampling of the 3013 packages produced at DOE sites.

R&D Challenges:

The diversity and limited characterization of impure materials makes it challenging to develop a comprehensive technical basis for safe storage criteria. In addition, there are limitations in the understanding of detailed phenomena and processes that occur in long-term storage packaging systems.

Effective surveillance is a balance between the scope of package examination, together with the number of packages examined, and the cost of that surveillance in terms of financial resources and personnel exposure. A major challenge will be the establishment of an effective program while minimizing the associated costs. Storage of radioactive materials and their reactive impurities at elevated temperatures for such long periods presents a number of technical challenges. These include the difficulty in adequately simulating the temperature environment (to assess temperature dependent effects) and the fact that some forms of corrosion (such as stress corrosion cracking) exhibit a different time dependence than "ordinary" corrosion. Technologies to permit the monitoring and interrogation of storage containers without violating the integrity of the package are limited. Surveillance and monitoring equipment and systems may be complicated by the need to allow for IAEA inspection of excess materials.

R&D Activities:

R&D activities are supporting the development of DOE Standards for nuclear material storage including testing representative samples of the inventory to assure that stability requirements can be met, and developing technologies to certify that stability has been achieved.

This effort also involves accumulating an inventory of representative materials to monitor in a shelf-life program, and developing a complex-wide resource for testing of sensor, measurement, and integration technologies for monitoring and surveillance of materials in storage. In addition, this effort will perform detailed investigations of the potential corrosion problems and other phenomena in this environment. Accelerated aging studies will be used to anticipate material chemical and physical changes under appropriate storage conditions. Efforts will begin to develop a predictive model to identify potential storage problems and determine ultimate storage limitations.

Accomplishments:

Materials Identification and Surveillance: Representative samples of inventories around the country have been accumulated and tested to verify that stability requirements can be met. It was determined that ~80% of the materials to be stabilized could not be certified with the baseline approach for moisture measurement, prompting the development of alternative certification approaches.

Moisture Measurement: Two additional techniques for moisture measurement in nuclear materials have been evaluated as an alternative to loss on ignition (LOI) testing. The super-critical fluid extraction method is fully developed and is being deployed at LANL, RFETS and Hanford. Development work continues on a neutron moderation method.

Storage Container Pressurization: Mechanisms for generating pressures in the sealed storage containers were evaluated and tested to confirm the adequacy of the DOE storage standard.

Gas Generation: A workshop on gas generation and mitigation in nuclear materials ranging from plutonium oxide to TRU waste and mixed waste has been established as a means of sharing available information and focusing future research.

Container Corrosion: The severity of corrosion as a threat to container systems has been evaluated to support the storage standard development and clarify surveillance requirements.

Update of DOE-STD-3013: The technical basis for storage of plutonium metal and oxide was expanded to include the ability to store impure items. The DOE Standard was updated accordingly.

Plutonium/Container Interactions: Experiments and associated finite element analyses have been completed, showing that phase transitions in the plutonium and plutonium-stainless steel interactions do not threaten the container integrity.

Surveillance of 3013-94 oxides and Metals: Oxides and Metals were sealed in 3013-94 type containers with bellows to monitor pressure changes. These containers have been monitored for over 2 years with no significant pressure change indicated.

Surveillance of 10-g items: Representative samples from RFETS and Hanford plutonium holdings have been stabilized and placed in instrumented containers. These containers have been monitored for over 2 years with no significant pressure change indicated.

Site Technology Support

Budget: FY99-$9.5M, FY00-$9.1M, FY00-$9.1M

Description. This work package consists of two interdependent activity areas, Core Technology and Site Technical Support. Core Technology addresses the need to understand the science underlying nuclear materials stabilization, packaging, transportation and storage. It provides basic research on the wide variety of nuclear materials and their interactions with other materials, particularly storage and transportation container materials, processing facility materials of construction, and so forth. The objective is to improve the understanding of observed phenomena and to increase the ability to anticipate problems. In addition, personnel involved in Core Technology efforts comprise a cadre of expert personnel available to deal with urgent site issues associated with development, demonstration and deployment of evolving technologies.

It is anticipated that during implementation of materials stabilization, packaging, shipping, and subsequent facility clean-up, and extending until all nuclear materials have been transferred to some other Program, EM sites and programs will have nuclear materials management activities that require routine technical support. Site Technology Support provides the expertise, coordination, and leadership to address these issues.

R&D Challenges:

The major challenge is to anticipate the site technical issues so that expert personnel and timely results are available to address their concerns. At the present, major areas of interest are related to issues that are expected to be important to storage and transportation of nuclear materials, as these are the areas that have the highest likelihood of causing delays in site closures.

Another key challenge is the result of the complexity and diversity of the nuclear material inventories, and the lack of comprehensive plans for managing all the materials that exist at DOE sites. One example is the handling of sealed sources. The issues involve the numbers of types of sources, their possible reuse, the advisability of recovering the contained SNM, etc.

R&D Activities:

A major element of this area is likely to be supporting implementation of stabilization approaches and support for de-inventory initiatives. Core Technology support includes the following areas for plutonium materials: actinide thermochemistry and phase behavior, actinide surface chemistry, corrosion, radiation chemistry and microdosimetry on impurities, plutonium-stainless steel interactions, and water interactions with U/Pu surfaces.. Another major element is expected to be a complex-wide approach to removing and dispositioning the wide variety of sealed sources at the closure sites. This might be extended to consider excess sealed sources at other sites, as well.

Accomplishments:

Stress Corrosion Cracking: Evaluated stress corrosion cracking (SCC) potential in a stainless steel container with chloride-containing oxide materials stabilized to the 3013 standard. Determined that moisture content is the critical parameter and that SCC should not threaten the 3013 container.

Plutonium-Stainless Steel Interactions: Evaluated the likelihood of eutectics or intermetallics occurring during 50 years of storage at expected 3013 storage temperatures. Determined there was no threat to the container.

Pressurization Mechanisms: In support of the DOE-STD-3013 revision, a kinetic model of the 3013 system was developed to explore phenomena that could contribute to pressurization.

Technical Basis for DOE-STD-3013: Many topical peer-reviewed reports have been generated to formalize the technical basis for the plutonium storage standard.

Site Support: Short-term support has been provided to RFETS to support disposition of residue items to WIPP and address problems with corrosion of drum vent filters.

Sealed Sources: Efforts to establish a coordination center for sealed sources have been initiated, and effort expended to resolve source-related issues at Mound and Fernald.

Directed Science

Budget: FY99-$2.1M, FY00-$1.8M, FY01-$0.5M

Within the Nuclear Materials investment portfolio, DOE funds research that advances science to solve environmental problems associated with unstable materials, such as plutonium metals and oxides, highly enriched uranium and nuclides of other actinide elements, and their long-term storage. Five subcategories of needs were identified in the area of nuclear materials:

- Nuclear materials stabilization, including forms for long-term disposal.
- Treatment methods for fissile materials.
- Characterization of fissile materials behavior; thermodynamics and kinetics; interactions with organometallics, surfaces and organic residues; stabilization and storage.
- Development of methods to verify integrity of storage containers, detect and/or prevent hydrogen buildup.
- Development and maintenance of robotic technology to minimize personnel exposure and handling of storage containers.

Between 1998 and 2000, eight research projects will be funded for a total amount of $5.5 million. The nuclear materials directed research portfolio is concentrated in the scientific areas of actinide chemistry, analytical chemistry and instrumentation, engineering science and materials science.

- *Actinide Chemistry:* Challenge of nuclear materials stabilization, as well as efforts directed at waste minimization/pollution prevention associated with continued actinide processing activities and waste-form and spent fuel stabilization assessment. A second study of actinide chemistry research is to develop a basic scientific (thermodynamic) understanding of actinide volatilization and partitioning/speciation behavior in the thermal processes that are central to DOE/EM's mixed waste treatment program.

- *Analytical Chemistry and Instrumentation:* Developing a new analytical instrument based on the principle of nuclear magnetic resonance (NMR) for in situ, in-field and in-process characterization and monitoring of various substances and chemical processes. Its development will involve application of the most recent advances in the fields of micromachining and microfabrication, permanent magnet materials and design, and microelectronics and signal processing.

- *Engineering Science:* Engineering science research in this area is specific to design, process and modeling to address criticality safety issues of interest in ongoing activities to dispose of DOE-owned spent nuclear fuel, and to assure criticality safety of fissile materials during facility remediation. Specifically, the research includes the utilization of novel computational techniques, improved nuclear data, and new analytical methods.

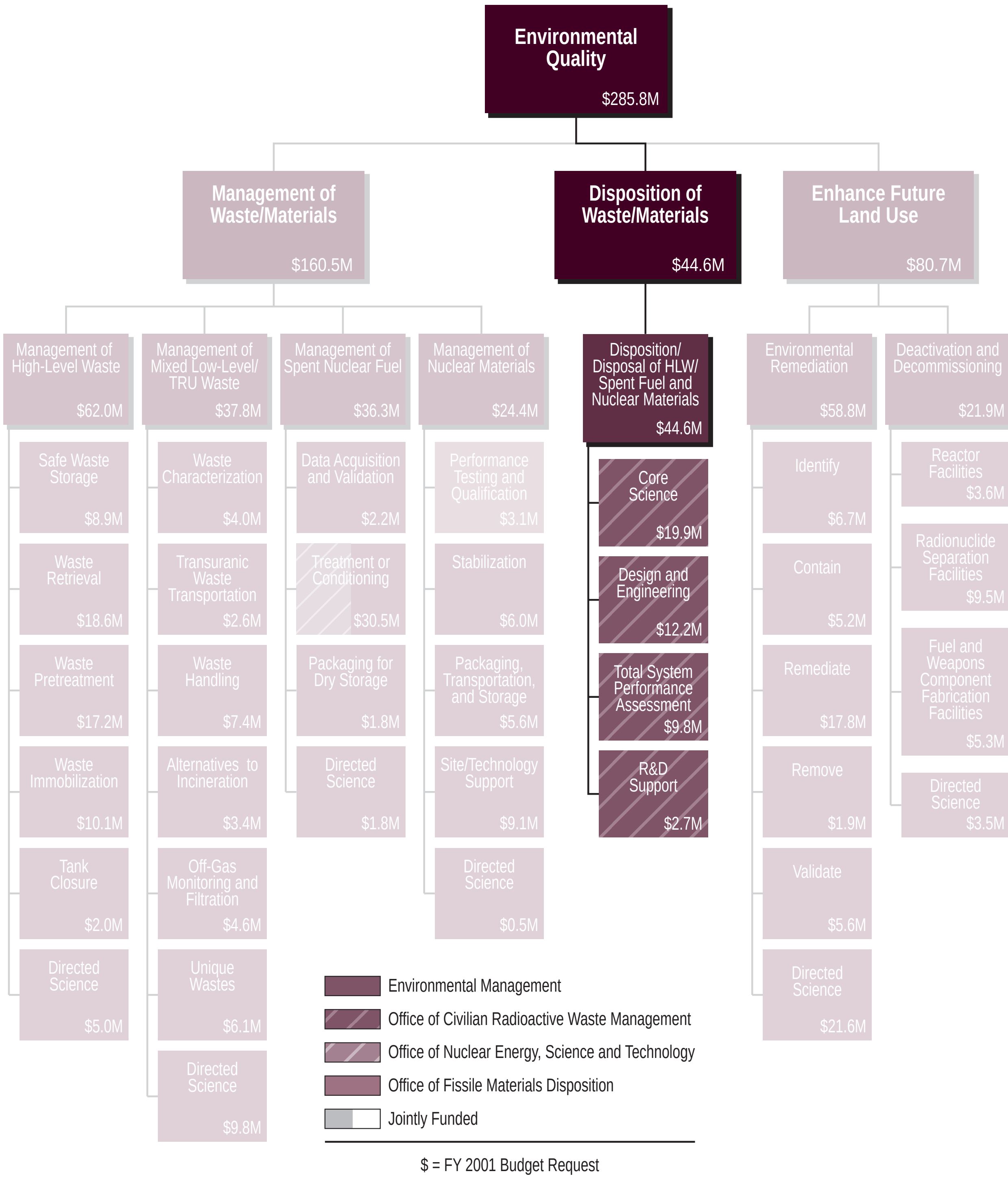
- *Materials Science:* Chemical and structural properties of storage materials, and radiation effects on storage materials. Research projects include physical and chemical properties of monazite, pyrochlore, zircon, and zirconolite as ceramic waste forms; distributions, solubilities, and releases of radionuclides and neutron absorbers in waste forms; and characterizing the effects of transmutation in a candidate waste form for cesium-137 by investigating samples of a cesium aluminosilicate mineral.

Budget Summary Table

(Dollars in thousands)

Program Activity	FY-1999	FY-2000	FY-2001
Performance Testing & Qualification	4,410	4,153	3,127
Stabilization	5,246	4,085	6,036
Packaging, Transportation & Storage	3,958	3,082	5,630
Site/Technology Support	9,509	9,100	9,079
Directed Science	2,141	1,780	526
Total	**25,264**	**22,201**	**24,399**

Chapter 7
Disposal



Chapter 7
Disposal

Table of Contents

Page

Overview

Definition of Problem Area

The *Nuclear Waste Policy Act of* 1982, Public Law 97-425, established the Department of Energy's (DOE) responsibility to provide for the permanent disposal of the Nation's high-level radioactive waste (HLW) and spent nuclear fuel (SNF), and directed that the owners and generators of these wastes bear the costs of disposal. The Act also established the Office of Civilian Radioactive Waste Management (OCRWM) to carry out a mission to provide for the disposal of SNF and HLW in a geologic repository, in a manner that protects the health and safety of the public and workers, and maintains the quality of the environment. The Civilian Radioactive Waste Management System (CRWMS) is being developed by OCRWM to fulfill that mission.

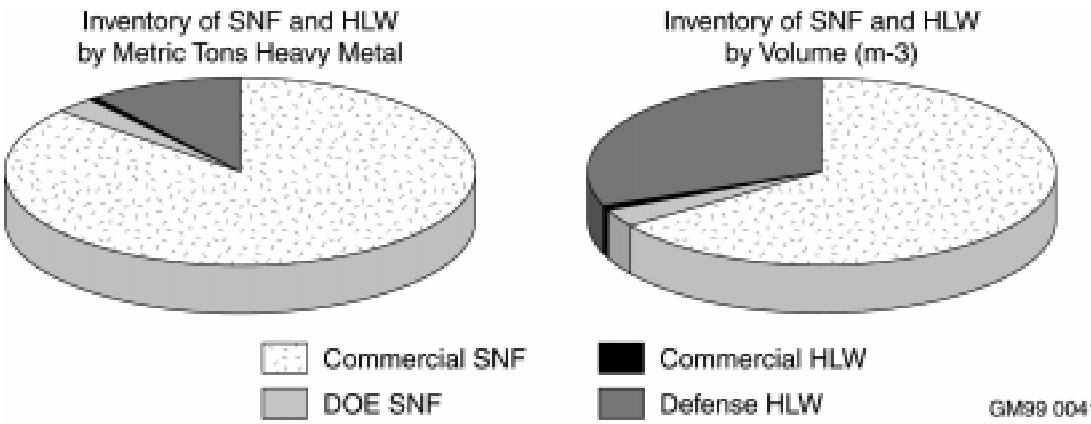
Since the enactment of the Act, the OCRWM Program has undergone some changes. The *Nuclear Waste Policy Amendments Act of 1987*, Public Law 100-203, designated the Yucca Mountain site in Nevada as the only site to be characterized to determine its suitability for a geologic repository. *The Energy Policy Act of 1992*, Public Law 102-486, directed the Environmental Protection Agency (EPA) to promulgate new health and safety standards for the Yucca Mountain site, based on the findings and recommendations of the National Academy of Sciences. Within one year of their promulgation, the Nuclear Regulatory Commission (NRC) is to revise its technical requirements and criteria for licensing the repository, based on those standards.

The types of waste that will be delivered to the repository for disposal consist of commercial spent fuel (including mixed oxide spent fuel), high-level waste (including immobilized plutonium), and DOE spent fuel (including Naval spent fuel). These wastes vary appreciably in form, radioactive content and condition. Due to age and degradation, some of the DOE spent fuel may require conditioning or stabilization before it can be accepted for disposal in the repository.

Most of the commercial spent fuel consists of fuel assemblies discharged from 78 pressurized water reactors (PWRs) and 40 boiling water reactors (BWRs). This spent fuel is located at 72 nuclear power plant sites and one independent storage site in 33 states. The total amount of spent fuel in inventory as of the end of 1998 is reported to be about 38,000 Metric Tons of Heavy Metal (MTHM) in PWR and BWR fuel assemblies. By 2040, the amount of spent fuel in inventory is projected to be 85,000 MTHM. The actual amount of spent fuel to be discharged could exceed the projected amount if reactor life extension programs are authorized by the Nuclear Regulatory Commission and implemented by the utilities. Conversely, the amount of spent fuel could be less than projected if reactors are shut down prematurely.

The high-level waste to be disposed of is immobilized and encased in metal canisters by both commercial and defense waste generators. It is estimated that about 22,000 canisters will be produced through 2035, including canisters that will contain immobilized surplus weapons-usable plutonium. However, there is currently some uncertainty in the exact number of high-level waste canisters that will ultimately be produced. Production of canisters of commercial and defense high-level waste has already begun at the West Valley Demonstration Project in New York and at the Defense Waste Processing Facility at the Savannah River Site, respectively. Wastes from these two facilities are in the form of borosilicate glass encased in stainless steel canisters. Production of waste canisters is also planned at both the Hanford Site and the Idaho National Engineering and Environmental Laboratory (INEEL). The reference waste form for the Hanford site is also a glass form, but final decisions on their characteristics and canister sizes have yet to be made. The final waste form for the INEEL has not yet been decided, but is currently under discussion.

DOE spent fuel includes fuel from defense production reactors, naval propulsion reactors, domestic and foreign research reactors, commercial reactors, Fort St. Vrain High Temperature Gas-Cooled Reactor, and debris from the Three Mile Island Unit 2 reactor. The DOE spent fuel inventory projected to the year 2035 totals about 2,500 MTHM, as shown in Figure 7-1.



	MTHM (or equiv)	**Volume (cu.m.)**
Commercial SNF	85,000 (84%)	38,048 (63%)
DOE SNF	2,500 (2%)	1,900 (3%)
Commercial HLW	640 (1%)	200 (<1%)
DOE HLW	13,000 (13%)	21,000 (34%)

Figure 7-1. Projected 2035 inventories of SNF and HLW by Metric Tons Heavy Metal and by Volume.

The current focus of the program is on the remaining work that needs to be done to support a site suitability recommendation in 2001, and if the site is approved by both the President and Congress, preparation and submittal of a license application to the NRC in 2002 for construction authorization for a monitored geologic repository at the Yucca Mountain site. To obtain an NRC 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. R&D work performed by National Laboratories is designed to support both the Site Recommendation and the license application. The work includes the development of a number of products for license application. These include reference designs for the repository and waste packages; improved models for the engineered and natural barriers and radionuclide transport through them; and evaluation of the probable long-term performance of the repository in its geologic setting.

National Context/Driver and Federal Role

The nuclear waste disposal program is charged with characterizing a site to determine its suitability for development as a repository, recommending to the president that the site be approved for repository development, and obtaining a license from the Nuclear Regulatory Commission to construct and operate the repository. Once licensed, the program is charged with taking title to nuclear wastes at civilian and government storage sites, transporting the wastes to a geologic repository, packaging the wastes in disposal containers, and emplacing the waste packages in underground drifts (tunnels).

Linkage to DOE Strategic Goals and Objectives

The Spent Fuel and High- Level Waste Disposal R&D efforts support the Environmental Quality strategic objectives as indicated in Figure 7-2.

Proof of performance of a monitored geologic repository is without precedent. The repository must isolate SNF and HLW from the human environment for over 10,000 years. To demonstrate that the facility can be safely deployed, DOE has conducted extensive research and evaluation activities that will provide reasonable assurance that the geologic disposal site will contain the wastes. Tests, studies, and analyses aimed at predicting performance of the natural and engineered barriers by simulating repository conditions have been developed. The work occurs in situ at repository depths, on the surface above the repository block, and in the laboratory. The scientific activities have been carefully planned to account for coupled processes affecting repository performance, namely thermal, hydrologic, chemical, and mechanical phenomena, over the range of expected near- and long-term conditions.

An objective of this investment area is to identify engineering materials, which will assist the engineered barrier designs to provide long-term containment of SNF and HLW planned for disposal in a geologic repository at Yucca Mountain. The multi-disciplinary R&D efforts focus on developing technological solutions to very complex problems associated with the disposal of the nation’s nuclear waste in a safe, environmentally sound, and cost-effective manner, a one-of-a-kind endeavor never before attempted. This information will be considered in any decision to recommend the site for repository development and will provide support for NRC issuance of a license for repository operation.

In addition, this environmental quality objective provides necessary information, in the form of acceptance criteria, which assists in the management, treatment or conditioning if necessary, and interim storage of SNF and HLW. Specifically, assurance that near-term decisions on managing SNF and HLW is compatible with ultimate disposition is a critical part of DOE's integrated role.

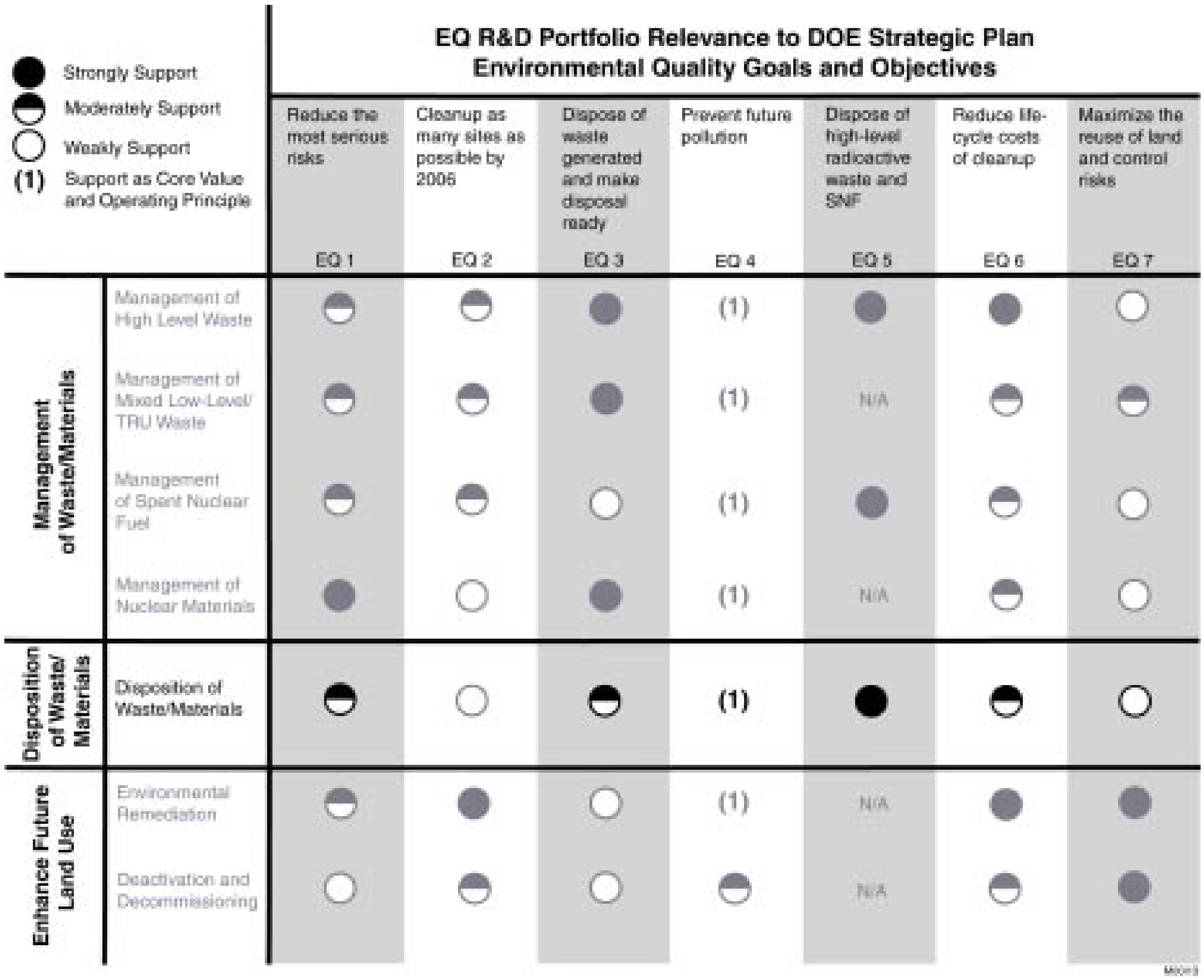


Figure 7-2. Relevance of disposal R&D investments to Environmental Quality goals and objectives.

Problem Area Uncertainties

The challenge in licensing a geologic repository is demonstrating a reasonable assurance of compliance with safety standards over many thousands of years. To reduce current uncertainties and increase confidence that a repository can contain and isolate waste for thousands of years, DOE is focusing its ongoing efforts on three major areas:

- Increasing the understanding of the key processes that are important to long-term performance of the repository such as the flow of groundwater and radionuclide transport through the engineered and natural barrier systems, including responses of these processes to the heat generated by the disposed waste.

- Improving the design of key engineered components of a repository such as testing and selection of improved waste package materials, waste-package emplacement design to achieve improved management of thermal load, and evaluation of backfill and drift-shield effectiveness.

- Increasing confidence in performance assessment models such as employing the improved process models with reduced uncertainties, using more realistic and reasonable parameters as opposed to highly conservative ones, and enhancing the capability of the Repository Integration Program (RIP) code to incorporate more of the details in the process models.

DOE also faces a challenge in selecting waste container materials (to include structural inserts and engineered criticality controls) that can withstand the range of conditions in the repository to prevent significant corrosion over the long time frames needed to ensure adequate waste containment and isolation. Investments are needed to examine the impact of container structural inserts and engineered criticality controls on the corrosion performance of the SNF forms and waste package.

R&D Investment Trends and Rationale

Figure 7-3 illustrates the current R&D investments for SNF and HLW disposal. Total investment levels are expected to decrease over the next few years as the total system performance assessment proceeds and support for licensing enters the final stages. The current approach to the characterization of Yucca Mountain distinguishes between tests required to evaluate site suitability, to support licensing, and to confirm the safety of the repository before closure. This distinction permits phasing of tests to achieve an earlier evaluation of the suitability of Yucca Mountain and will result in less future R&D funding.

The decrease in many of the long-term R&D objectives will be reflected by the shift from the scientific investigation phase to the design and regulatory phase. Many near-term R&D objectives are related to development of the Site Suitability determination. OCRWM is continuing to build on the momentum of the *Viability Assessment for a Repository at Yucca Mountain, Nevada* report issued in FY 1999. The Final Environmental Impact Statement (FEIS) is scheduled to be issued next year and will assist the Secretary in making a decision on whether to recommend the site to the President.

A decision on the suitability of Yucca Mountain and submittal of the Site Recommendation Report by the Secretary to the President in July 2001 are the most critical in the Program's history. If the site is qualified for application to the U.S. Nuclear Regulatory Commission (NRC) for a construction authorization, the President will then submit a formal site recommendation to Congress.

Investments will then shift to the licensing effort. Once a site designation becomes effective, the Secretary will submit to the NRC a License Application in early 2002 based on a particular facility design. Support to licensing will include performance confirmation activities and updates to ongoing research and modeling in support of licensing hearings.

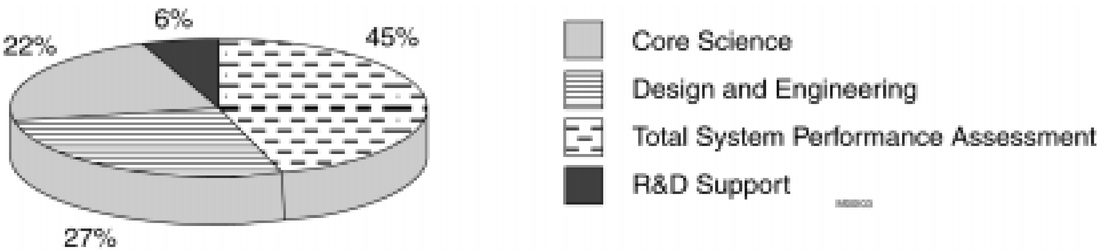


Figure 7-3. Cumulative investment in disposal areas over 3 years (FY 1999–FY 2001).

Key R&D Accomplishments

Viability Assessment

The Program is implementing the scientific and technical activities at the Yucca Mountain Site Characterization Project in accordance with the recently issued *Viability Assessment for a Repository at Yucca Mountain, Nevada*. In FY 1999, the Program continues to gain momentum toward a Secretarial decision on a Site Recommendation and License Application by:

- Publishing the Viability Assessment to support policy decisions on proceeding toward Site Recommendation and License Application.
- Completing the repository and waste package designs for use in developing the Total System Performance Assessment and other documentation.
- Completing the formal, independent peer review of the Total System Performance Assessment documentation for the Viability Assessment.
- Completing the Draft Environmental Impact Statement (DEIS).

Core Science

Understanding the Effects of Heat on Repository System Performance. A subject of long-term studies is how heat generated by radioactive decay of waste would alter the surrounding environment. Changes in rock mineralogy, mechanical properties, rock and water chemistry, and site hydrology would affect the rate at which waste packages degrade and radionuclides are released and the mechanisms and pathways by which radionuclides could be transported.

To closely examine these phenomena, DOE's Lawrence Berkeley, Lawrence Livermore, Sandia, and Los Alamos National Laboratories are conducting three tests that use electric heaters to simulate heat generated by waste. Very different in scale, all three tests contribute data on the effects of thermally driven hydrologic, chemical, and mechanical processes in rock. Scientists use these data to develop models of how the engineered and natural barriers of a repository system at Yucca Mountain would respond to heat.

Significant results to date from the single heater test and the drift test scale include identification of conduction as the dominant heat transfer mechanism and the preliminary indication that rock porewater mobilized by the heat tends to drain by gravity, via fractures in the rock mass, to below the heated region rather than staying perched above it.

Building a Three-Dimensional Model of the Site. Data from site investigations were interpreted and extrapolated to build and refine a three-dimensional, integrated model of site hydrogeology—in effect, a picture of what we know about rock layers, faults, rock properties such as porosity and hydraulic conductivity, and mineralogy, including the presence of zeolites. In FY 1999, important validation of our understanding of the site came with confirmation of our predictions of the geologic features that we would encounter in excavating the cross-drift and drilling two boreholes from the surface of the site to a depth of over 2,500 feet.

Benefiting from Peer Review. OCRWM used peer review to verify the appropriateness of the methods and approaches we use in investigations to develop predictive models on performance of the engineered and natural barriers. In FY 1999 we implemented a sampling and analysis program, using boreholes drilled from within the Exploratory Studies Facility and cross-drift as sources of samples. Sampling was completed and analyses are currently underway. Peer reviewers completed their review of the approach and methodologies we are using to model radionuclide transport through the unsaturated zone beneath the potential repository. The panel observed that currently there is no preferred alternative model to ours. They recommended several ways to technically enhance and validate our model. We are evaluating these recommendations and developing a plan to implement them.

Design and Engineering

Enhancing Repository Design. A major Fiscal Year 1999 accomplishment was the adoption of a repository design concept that enhances the design used in the viability assessment. A number of the design enhancements we adopted had been urged by the Nuclear Waste Technical Review Board. A key feature of the enhanced design is a lower repository temperature, achieved through a set of thermal management techniques. Because the heat generated by high-level radioactive waste introduces uncertainties into estimates of repository performance, lowering the temperature would increase confidence in our total system performance assessment calculations.

The revised design preserves the flexibility for future generations to determine when to close the repository. This design concept will be the basis for the total system performance assessment that will support determinations concerning site recommendation, and it will serve as the starting point for the design concept presented in a license application.

Designing Waste Packages and the Drip Shield. In FY 1999 OCRWM adopted a set of enhanced repository design features that will serve as the basis for the design that will support the determination whether to recommend the site. Waste packages will make a major contribution to the repository system's ability to isolate waste and retard the migration of radionuclides. Our new waste package design boosts performance by changing the materials from which it is fabricated. We determined that a waste package made with Alloy-22, a highly corrosion resistant nickel-chromium-molybdenum alloy, on the outside and a reinforcement cylinder of 316-series stainless steel on the inside would offer greater resistance to corrosion and more confidence in predicting corrosion rates than the viability assessment design.

We completed two studies related to criticality. One supplements the *Disposal Criticality Analysis Methodology Topical Report* (which explains how we will evaluate waste packages to demonstrate criticality safety during the post-closure period) by presenting the results of additional benchmarking exercises to validate models used to predict the composition of commercial spent nuclear fuel. The second study presents a process for evaluating criticality safety during the pre-closure period.

Dry Transfer System for Spent Nuclear Fuel. The dry transfer system was developed to provide a low-cost way for utilities to handle spent nuclear fuel assemblies in the absence of a spent nuclear fuel storage pool. It will enable utilities to transfer individual fuel assemblies between a conventional to-loading cask and a loaded canister in a shielded overpack, or to accommodate transfers between two conventional casks.

Under a $4.5 million cold demonstration project (i.e., conducted without radioactive materials), testing began on a prototype dry transfer system. Completed in October 1999, the demonstration validated the performance of systems and components, determined design adequacy, confirmed system and operational capability to recover from off-normal conditions, and provided loading cycle time and overall system throughput rates. It also produced information on equipment fabrication costs through actual purchases under a rigorous quality assurance program.

Total System Performance Assessment

The Repository Safety Case. In preparing the viability assessment, we defined a conceptual framework for how to demonstrate the safety of the repository system. The work completed in FY 1999 focused on improving our understanding of what we believed were the most significant factors affecting repository system performance. The insights of our peer reviewers and oversight bodies also shaped our research agenda, which principally concerned the following:

- Volumes and rates of, and mechanisms for, water infiltration and seepage in to the repository.
- Pathways and mechanisms for transportation of radionuclides through the saturated zone.
- The nature of interactions between engineered barriers and natural processes.

- How candidate waste package materials would perform over long periods of time, under varying conditions.

- How enhanced repository design concepts could improve safety.

- How process models could more accurately represent site conditions and waste package performance.

To reduce uncertainties, we conducted tests, gathered data, assessed alternative designs, and conducted analyses to determine which uncertainties matter most and which are most sensitive to new information that could be obtained from further field and laboratory testing.

<u>Performance Assessment</u>. Working within the framework of the repository safety strategy, performance assessment integrates site investigations, laboratory studies, expert judgment, and repository design into a set of numerical models that represent the total repository system. The total system model is used to simulate how a repository at the site might perform under a range of conditions over thousands of years. We use it to evaluate repository system performance against proposed regulatory criteria, evaluate the contribution of each engineered barrier to performance, and identify uncertainties in our understanding of performance. In FY 1999 we refined the viability assessment models to reflect new information from site investigations and laboratory studies, advances in modeling physical processes at the site, and an enhanced repository design.

<u>Understanding the Unsaturated Zone</u>. The unsaturated zone comprises areas of rock above the water table that would house the repository. Performance assessments for the viability assessment identified seepage of water into emplacement tunnels and onto waste packages as a possible cause of waste package degradation and eventual release of radionuclides. determining under what conditions, in what quantities, and at what rates moisture would seep into drifts and onto waste packages is the subject of continuing study. Our underground experiments provided data crucial to understanding and quantifying how groundwater moves through Yucca Mountain. Major experiments involved measuring seepage at several locations and under two general types of conditions: ambient, in which we measure the amount of natural infiltration of water into test areas, and forced, in which we introduce into test areas and measure the resulting infiltration.

In FY 1999, we constructed Alcove 7 within the Exploratory Studies Facility to test deep percolation and seepage through the highly fractured rocks of the Ghost Dance Fault. This alcove is 200 meters (660 feet) long and approximately 220 meters (726 feet) below the surface. Bulkheads within the alcove isolate faulted and non-faulted sections to limit the drying effects of the ventilation system. Despite this isolation, no seepage has yet been observed in this alcove.

Forced-flow experiments enabled us to investigate how underground openings similar to waste emplacement tunnels alter the groundwater flow field, possibly diverting water into surrounding rock. These experiments examined the distribution and amount of seepage that might occur in waste emplacement drifts, using several niches at repository depth in the

Topopah Springs tuffs and one alcove closed to the surface of the site, in the Tiva Canyon tuffs.

Nuclear Waste Technical Review Board

In April 1999, the Nuclear Waste Technical Review Board published a report, *Moving Beyond the Yucca Mountain Viability Assessment*. The Board concurred that work to determine site suitability should proceed and that planned studies are technically feasible and likely to produce useful information. The Board also recommended further work, including modifications to repository design that converged with alternatives the Project is evaluating.

Key R&D Issues

The repository for SNF and HLW will be the nation's second geologic repository. The nation's transuranic waste repository, the Waste Isolation Pilot Plant (WIPP), was finally opened this year, over a decade behind the original schedule. Based on the experience with WIPP, there will be a continued and possibly increased need for research in support of licensing and to answer legal challenges over the next decade.

Centralized interim storage of SNF and HLW remains a possible alternative while licensing and preparation of the repository proceeds. The capability to accelerate transportation of SNF and HLW to a receiving facility must be maintained, including supporting research and development.

If Yucca Mountain is determined to be suitable for a geological repository, development of the operational infrastructure will be placed on a fast track to support operations in 2010. Research and design of systems already underway as part of the EIS and licensing process will accelerate.

A number of questions remain concerning acceptability of waste forms for nuclear materials dispositioning. The geologic repository is one solution for a portion of these materials, but decisions on which materials will not be finalized for some time. Continuing research and modeling of repository system impacts due to disposition of varying quantities of different materials and waste forms will be necessary.

Problem Area R&D Program

Budget: FY99-$59.2M, FY00-$47.2M, FY01-$44.6M

Program Description

DOE investigations of the Yucca Mountain site have resulted in a substantial understanding of the site, a preliminary reference repository design, and assessments of the performance of the repository system. These work products are of the type needed to support site recommendation and submittal of a license application. However, additional technical work is needed to complete the postclosure safety case, support the preclosure safety case, and support remaining design decisions.

DOE is funding multiyear tests of likely waste package materials under relevant repository conditions. The tests are aimed at identifying any localized corrosion mechanisms and developing models to predict long-term corrosion of waste package materials. Other testing is planned on specific waste forms to understand their corrosion and dissolution properties under relevant repository conditions.

In order to understand how the natural and engineered barrier system would respond to the waste-generated heat, DOE is also funding a multi-year drift-scale heater test and completing analyses of the large block and single-heater tests already completed; and performing several unique flow tests underground at the Yucca Mountain site in order to further define how groundwater flows under the site geologic conditions.

Core Science

Budget: FY99-$26.3M, FY00-$21.0M, FY01-$19.9M

This work studies how the natural environment within the immediate vicinity, or near-field, of the waste packages will be affected by excavation of the waste emplacement drifts and other underground openings, by the heat generated by the waste, or by the introduction of nonnative materials. The work also will address the extent to which heat generated by the waste will create an altered zone of rock away from the waste packages. The studies will address the effects of coupled (or interacting) thermal, mechanical, hydrological, and chemical processes. Finally, core science will help DOE to understand the long-term geologic processes, both anticipated to occur and unlikely but possible to occur, that affect the movement of radionuclides over many thousands of years far from the planned disposal site.

Remaining work includes laboratory tests and modeling to improve simulations of the performance of engineered barrier system design options; compare the performance of different materials that might be used in a repository; improve evaluations of the mechanical stability of ground support materials; refine evaluations of thermohydromechanical coupled effects on engineered barrier system design options and rock stability; refine evaluations of thermohydrochemical coupled effects on seepage into drifts and engineered barrier system performance; improve specification of the near-field chemical environment; and update models of flow and transport through the altered zone.

Specific activities include:

- Collecting and testing geologic, hydrologic, geochemical, and geomechanical site characterization and performance confirmation data from the subsurface and surface. The ongoing collection of data through FY 2001 will include data from short- and long-term testing programs (both on the surface and underground) that produce quality field and laboratory measurements for use in conceptual and numerical process models and engineering design calculations. These data will provide an increased understanding of the hydrology, geology, and geochemistry of the site and supply information on how thermal, hydrologic, chemical, and mechanical processes behave in the immediate natural environment.

- Collecting and monitoring environmental data to ensure compliance with regulatory requirements; testing material performance; planning, formulating, modeling, and testing scientific hypotheses; completing models and reports and collaborating with Russian scientists and engineers on characterization issues of mutual interest. The data collected will be used in the documentation that supports the major program products (e.g., Environmental Impact Statement, Site Recommendation Statement, License Application).

- Under a cooperative agreement, the University and Community College System of Nevada will continue to provide the public and the Yucca Mountain Site Characterization Office with an independent, unbiased body of scientific and engineering data concerning the study of Yucca Mountain as a potential high-level waste repository.

Thermal testing studies how the heat produced by deposited waste would affect mechanical, hydrological, and chemical characteristics of the emplacement drifts and surrounding rock. The objectives are to understand how mechanical, hydrological, and chemical processes are affected by heat and how they interact with one another under the influence of heat. The results will be factored into models that represent the rock layers and the heat flowing through them and provide additional information about the features of the rock that allow, enhance, or retard the movement of heat.

Specific activities supporting thermal testing include:

- Large block test. Characterizing the large block of rock at the surface near Yucca Mountain that was heated for more than a year and is now in a cooling phase.

- Drift-scale thermal testing. Conducting a drift scale test that involves heating and monitoring a drift and surrounding rock within the Exploratory Studies Facility, and planning and implementing a field thermal test in the cross drift excavation. In Alcove 5, at the Yucca Mountain Exploratory Studies Facility, a special integrated test facility has been designed and has begun operations to help scientists understand coupled interactions of mechanical, geochemical, and hydrologic effects due to the thermal effects of high-level waste and spent nuclear fuel on groundwater flow and chemistry. This creative experiment is designed to simulate long-term, environment-specific interactions between key physical and chemical processes to support scientific understanding of rock, water, and waste interactions.

- Single Heater test. Completing the analysis of data from the single heater test, which heated rock within the Exploratory Studies Facility and then allowed the rock to cool.
- Modeling and analysis of thermal-hydrological-mechanical-chemical (THMC) processes.

Budget: FY99-$16.2M, FY00-$12.9M, FY01-$12.2M

Design and Engineering

R&D Challenge. DOE faces a challenge in selecting waste container materials (to include structural inserts and engineered criticality controls) that can withstand the range of conditions in the repository to prevent significant corrosion over the long time frames needed to ensure adequate waste containment and isolation. Investments are needed to examine the impact of container structural inserts and engineered criticality on the corrosion performance of the SNF forms and waste package.

The upward trend from FY 1999 to FY 2000 reflects increased design activity to support a decision whether to recommend the site draws to a close and testing for License Application increases.

In FY 1999, refinement of the preliminary repository and waste package designs continued to provide more detail. Three key design options that would enhance repository performance are being evaluated for the Working Draft License Application. These options include: backfilling the emplacement drifts; installing drip shields over the waste packages to keep water from contacting the waste package; and coating the waste packages with a ceramic material. In addition, several key design alternatives are being evaluated for the Working Draft License Application as proposed in the Viability Assessment, Volume II. These alternatives include continuous ventilation of the wastes, both pre- and post-closure; different waste package designs and materials (depending on the waste type); lower thermal loads in the underground emplacement drifts; self-shielded waste package designs that eliminate most underground remote handling operations; and different waste package emplacement configurations (in-drift, in-floor emplacement).

The principal factors affecting the postclosure performance of the waste package include:

- Water dripping onto the waste package.
- Humidity and temperature of the waste package environment.
- Chemistry of water on the waste package.
- Integrity of the carbon steel outer barrier of the waste package.
- Integrity of the high-nickel alloy inner barrier of the waste package.
- Integrity of spent nuclear fuel cladding.
- Dissolution of the uranium oxide and glass waste forms.

Spent nuclear fuel and high-level radioactive waste glass will be tested under conditions anticipated in the repository. These tests will provide data on dissolution and release rates for film flow and dripping water conditions. In one test, spent nuclear fuel, both in cladding and crushed in a thin film, will be tested for cladding integrity, bounding alteration, and release rates. In a separate test, colloids that form during the degradation of spent nuclear fuel and glass samples will be analyzed. Another test assesses how dripping solutions interact with potential waste package and emplacement drift materials such as crushed tuff, concrete, and corroded metal products.

Degraded glass-type waste forms will continue to be tested semiannually with actinide-doped material coming from the Defense Waste Processing Facility and the West Valley Demonstration Project. Parametric tests will continue including evaluating surface area, waste chemistry, and temperature. The tests will be adapted to assess interactions between leachates and waste package component materials. The reaction rate for glasses of the Defense Waste Processing Facility type with water vapor will be determined as a function of temperature.

Oxidation will be measured using thermogravimetric analysis techniques, which quantify changes in sample weight as a function of time and temperature. These tests will help in understanding, quantifying, and modeling how uranium dioxide fuel oxidizes (kinetics).

Dissolution rates will be obtained from flow-through dissolution tests on spent fuel samples under controlled chemistry and temperature conditions. The data will be used in developing models and as input for analyzing and interpreting results from the unsaturated drip testing. In addition, the bounds for release rates of highly soluble fission products will be obtained.

Colloids, extremely small particles suspended in water, are important to understanding transport through the unsaturated zone because radionuclides may bind to them. Laboratory studies are planned to address uncertainties about the formation and stability of colloids and their interactions with radionuclides, particularly plutonium.

Testing specimens with the same characteristics as the waste package helps develop understanding of how these materials degrade. The materials to be tested will include high-nickel and titanium-based alloys including crevice corrosion-resistant candidates Alloy 22 (nickel based) and titanium grades 7 and 16 (titanium based with small additions of palladium). Testing will be done in various aqueous solutions and at different temperatures, with samples being removed at planned intervals. Multiple samples will be used for statistical purposes. Candidate materials will be exposed to potential aqueous environments for at least 5 years. Different configurations of specimens will be used to investigate all forms of corrosion behavior. The test solutions of specimens will be analyzed on a continuing basis for evidence of microbial growth and its effects on corrosion. The results from these tests will be used to develop process models. An enhanced phase stability model will be developed for microbiologically influenced corrosion, pitting and crevice corrosion, stress corrosion, general corrosion and oxidation, and galvanic corrosion. The degradation of the metallic materials comprising the waste packages will be modeled as a function of time. Modeling will progress from a preliminary level to a more advanced stage as relevant test results become available and can be incorporated.

Thermogravimetric analysis studies address materials susceptible to accelerated corrosion in humid conditions. The controlled humidity experiments study the degradation of the susceptible materials at less than 100 percent relative humidity and a constant temperature so that degradation of the waste package can be modeled.

Long-term corrosion tests are underway for the materials that comprise the outer (corrosion allowance) and inner (corrosion resistant) barriers of the waste package. These materials are being tested under a range of representative repository conditions. Specimens are exposed in the vapor phase (humid conditions), at the water line (partially immersed), and fully immersed (underwater). The interaction between the corrosion-resistant and corrosion-allowance materials (barriers) when the waste package is cracked or breached will also be assessed.

The viability of ceramic materials as an alternative or augmentation for the inner or outer barriers of the waste package or for use in drip shield applications may be evaluated. Ceramics would best be used as coatings on metallic material. Tests will be conducted to determine the adhesive strength of the coating and its ability to withstand thermal and handling loads. Critical factors in assessing the effectiveness of ceramic coatings include the ability to maintain an impervious barrier of protection for the material being coated (substrate). The permeability and density of the coatings as a function of the type of ceramic and the way it is applied will also be determined. Samples of various thickness, structure, and composition will be exposed to corrosive conditions to find out how much protection the coatings provide. Of particular importance is how porous or cracked regions of the coating affect the long-term behavior of the substrate metal.

Specific activities supporting design and engineering include:

- Thermogravimetric analysis on corrosion resistant materials, and ceramic and ceramic-coated materials.
- Long duration galvanic specimen testing.
- Critical potential measurements.
- Assessment of potential for microbiologically influenced corrosion (MIC).
- Phase stability microstructural evaluation.
- Ceramic materials testing and modeling.
- EBS materials testing and modeling.
- Testing and modeling of the engineered barrier system (EBS).

Current regulations require that nuclear criticality be prevented or its potential minimized in all phases of repository operations and after permanent closure. Two important aspects of the criticality analysis are securing NRC approval for using burnup credit to demonstrate criticality control, and evaluating the effectiveness of measures to control criticality. Technical work to be completed regarding nuclear criticality includes:

- Completing work to improve methods including determination of the range of parameters to describe the potentially critical configurations, refinement of the method for generating probability distributions of parameters affecting criticality, and estimation of consequences of potential criticalities.

- Completing work to justify the use and estimate the amount of burnup credit. Though the techniques being developed rest on scientific fact and well-understood theory, they do go beyond current practice in NRC licensing proceedings.

Total System Performance Assessment

Budget: FY99-$13.1, FY00-$10.4M, FY01-$9.8M

Process models are mathematical representations of features, events, and processes that could affect how the repository functions. Taken together, the abstractions of the process models comprise the Total System Performance Assessment model used to evaluate future doses of radiation to persons living near Yucca Mountain for thousands of years into the future. There are process models for the interaction of heat and water in the repository; the near-field geochemical environment; waste package degradation; waste form degradation and the mobilization of radionuclides and other contaminants of concern by water; transport of radionuclides through engineered barriers; unsaturated zone water flow; transport of radionuclides through the unsaturated zone; saturated zone flow and transport; disruptive processes and events; and the movement of radionuclides throughout the biosphere, the region in which flora and fauna are present.

Specific activities supporting Total System Performance Assessment include:

- *Geologic Framework and Disruptive Events:* This work includes improving the characterization of the geologic framework of the site and improving the evaluation of natural processes and events that could change the physical and chemical properties of rock and water at the site. Much of the effort concentrates on incorporating new data into and refining the three-dimensional model that represents the rock formations and geologic structures comprising Yucca Mountain. This work includes studies providing additional site-specific soil and rock property data needed to finalize repository design to account for potential seismic disturbances.

- *Unsaturated Zone Process Testing:* This work addresses changes in climate and their effects, infiltration of water through surface soils and near-surface rocks to rock layers below, and movement of water downward through the unsaturated zone (the rock mass above the water table). The objectives are to continue to monitor and improve the understanding of how and at what rates water passes through the unsaturated rock and to improve predictions of the conditions under which water may seep into the waste emplacement drifts.

- *Saturated Zone Process Testing:* This work addresses the flow of water in the saturated zone, located below the water table. The results will provide additional information about the features of the rock that allow, enhance, or retard the movement of water. This information will be factored into models that represent the rock layers and the water flowing through them. The way water mixes in the different layers in the saturated zone is of particular interest because it controls the amount by which radioactive elements (radionuclides) in the groundwater will be diluted, which in turn directly affects potential doses to exposed persons.

Accomplishments:

- Published the Viability Assessment of a Repository at Yucca Mountain to support policy decisions on proceeding toward Site Recommendation and License Application.

- Performance measures included simulated doses to affected populations and/or releases at specified boundaries. The Total System Performance Assessment--Viability Assessment also presented sensitivity and uncertainty analyses to define key parameters that impact total system performance and to evaluate the significance of alternative assumptions in the overall prediction.

- Impacts of the Total System Performance Assessment--Viability Assessment on the scientific process models and design products were described, and recommendations were made for modifications that could significantly reduce uncertainty in the final does calculations in the next performance assessment iteration.

As directed by Congress in 1997, the Program has completed a viability assessment of the Yucca Mountain site in 1998. The viability assessment describes the preliminary design concepts for the repository and waste packages; a quantitative assessment of the probable long-term behavior of the repository in its geologic setting; a plan and cost estimate for the remaining work required to complete a license application to the Nuclear Regulatory Commission for construction authorization; and an estimate of the costs to construct and operate the repository in accordance with its design concept.

Performance assessment analyses of the preliminary waste package and repository designs indicate that:

- For 10,000 years after the repository is closed, people living near Yucca Mountain are expected to receive little or no increase in radiation exposure.

- The maximum radiation exposures from the repository is expected to occur after about 300,000 years. People living approximately 20 kilometers (12 miles) from Yucca Mountain at that time might receive additional radiation exposures equivalent to present day background radiation.

- Based on the viability assessment, DOE believes that Yucca Mountain remains a promising site for a geologic repository and that work should proceed to support a decision in 2001 on whether to recommend the site to the President for development as a repository.

R&D Support

Budget: FY99-$3.5M, FY00-$2.8M, FY01-$2.7M

R&D support includes maintenance of technical databases, sample management, quality control of project activities, external peer reviews of products, and activities associated with project management. R&D support ensures that all R&D efforts are integrated among the various project participants, thereby achieving well-coordinated results and minimizing duplication.

Specific major activities related to Support Services include:

- *Environmental Impact Statement Technical Support* for the Environmental Impact Statement contractor to prepare the draft and final Environmental Impact Statements using technical data developed by OCRWM and the Management and Operating contractor.

- *Quality Assurance Technical Support* in complying with NRC requirements, developing and maintaining the OCRWM Quality Assurance Requirements and Description (QARD), developing Quality Assurance procedures, maintaining QA databases, developing and conducting OCRWM QA training and maintaining QA training records. Conduct audits, surveillance, on-site inspections, tests, and reviews of participant and vendor activities.

- *Management & Technical Support Services* that provides an independent technical review capability of the work accomplished by the DOE National Laboratories and the management and operations contractor conducting the characterization of Yucca Mountain and the design and licensing of the potential geologic repository.

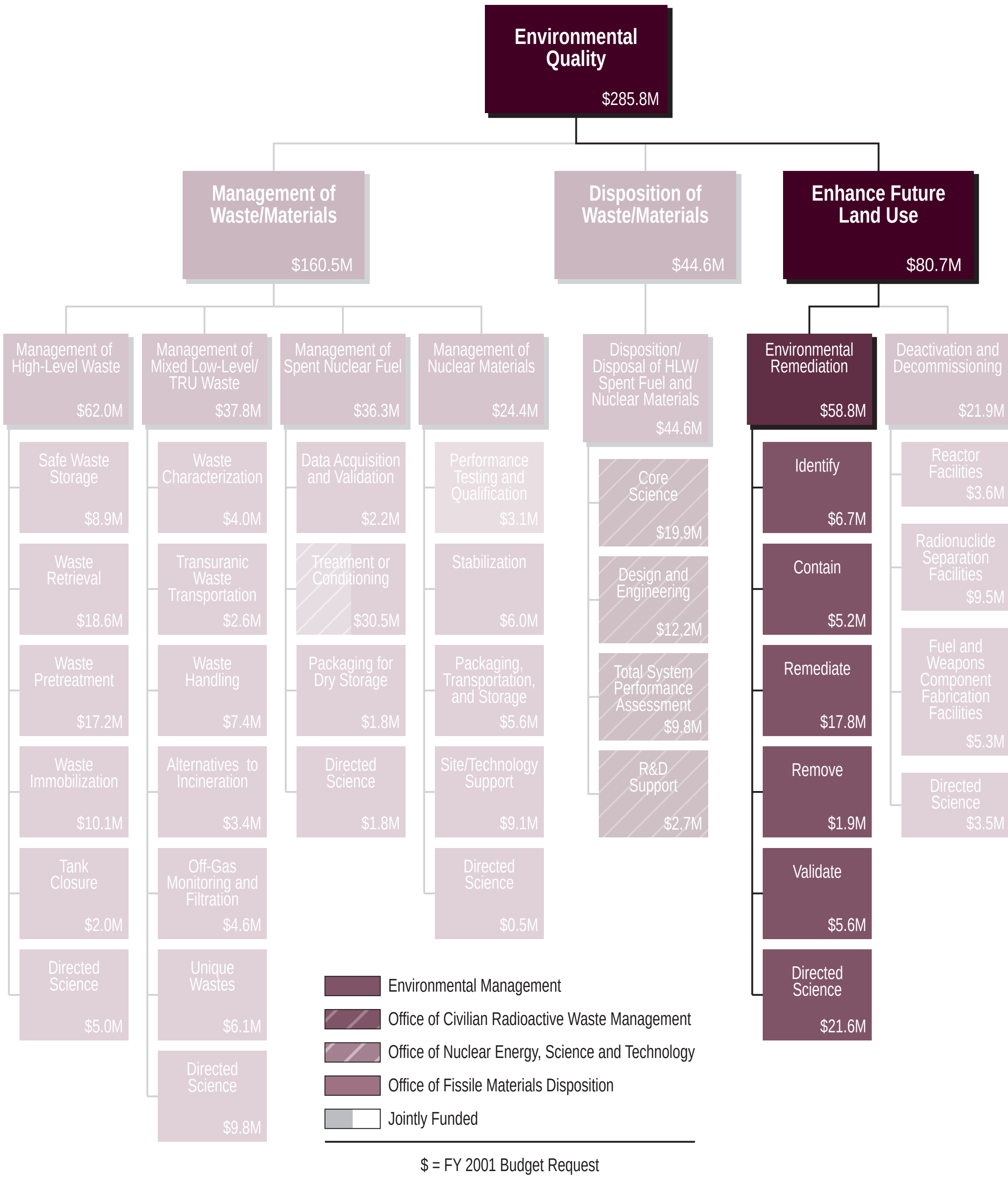
- *Technical Analysis Support Services* provide analysis of spent fuel projections.

Budget Summary Table

(Dollars in thousands)

Research Area Function	FY 1999 Actual	FY 2000 Appropriated	FY 2001 Request
Core Science	26,348	21,026	19,869
Design and Engineering	16,219	12,947	12,235
Total System Performance Assessment	13,059	10,421	9,847
R&D Support	3,537	2,824	2,668
Total	**59,163**	**47,218**	**44,619**

Chapter 8
Environmental Remediation



Chapter 8
Environmental Remediation

Table of Contents

Page

Overview

Definition of Problem Area

Environmental Remediation involves the removal or mitigation of radioactive and/or hazardous materials and pollutants in soil, fractured bedrock and groundwater. The primary functions 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 of solid radioactive and hazardous wastes are buried in the subsurface throughout the DOE complex. The largest contamination challenges are found at the Idaho, Oak Ridge, Hanford, Rocky Flats, and Savannah River sites. Contaminants are located in the subsurface both above the water table (in the vadose zone) and below the water table (in the saturated zone). Reflecting the geology of the United States, contamination at DOE sites is present in a wide variety of geologic matrices. An estimated 75 million cubic meters of soil and 475 billion gallons of ground water are contaminated and will 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. Estimated Environmental Remediation costs are shown in Figure 8-1.

Sources of contaminants include plumes emanating from seepage basins, cribs, leaking tanks, and landfills; airborne releases deposited on the soil surface by wind or precipitation; wells used for underground injection of wastes; and waste-disposal areas with contaminants that are mobilized by precipitation, ground water, or surface water flowing through the site. Burial of low-level radioactive waste, mercury, lead, spent solvents, explosives, and contaminated equipment has resulted in large inventories of poorly characterized land-stored waste.

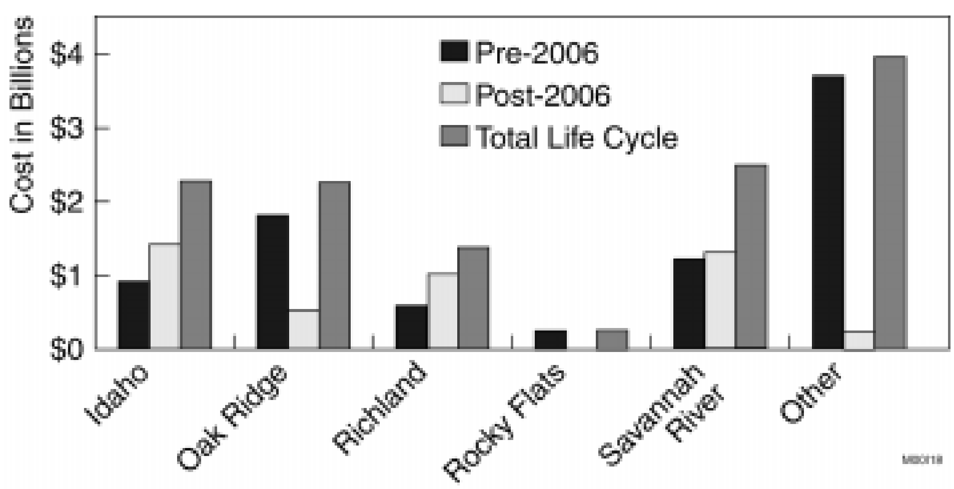


Figure 8-1. Through 2006, Post-2006, and Life Cycle costs for managing environmental remediation costs.

National Context/Drivers and Federal Role

Based on the environmental concerns, the Federal Government is investing in remediation where the industry believes the risk is too high to be addressed in the private sector, or where the Government has unique R&D capabilities.

Many DOE sites have entered into a number of interagency compliance agreements with the EPA and state agencies. These agreements have legally enforceable milestones. Some of these sites have completed the remedial investigation/feasibility study process and have signed records of decisions that specify cleanup technologies, performance standards, and deadlines. Some DOE sites have also entered into enforceable agreements that address the management of radioactive waste and mixed wastes. As a result of these agreements, the DOE may be constrained to work within imposed schedule and performance requirements and may not, therefore, have the flexibility to implement maturing technologies at all sites with similar contaminant/environment combinations.

Notwithstanding the preceding considerations, there is widespread recognition among regulators that budgetary constraints are real and that cooperation is needed to achieve remediation and waste management goals. Innovative technologies can provide an opportunity to accomplish these goals in a more cost-effective and timely manner. Therefore, the regulators must be involved throughout the technology development process and must help to identify and resolve regulatory issues.

Linkage to DOE Strategic Goals and Objectives

The environmental remediation R & D activities support the accomplishment of Environmental Quality strategic objectives at the levels indicated in Figure 8-2.

An Integrated Program Plan has been prepared to address the complex set of technology needs in a fashion that meets the four major objectives for investments in science and technology as defined in the *EM Research and Development Program Plan:*

- Meet high-priority end-user needs.
- Reduce costs [of costliest problems].
- Reduce technological risk.
- Accelerate technology deployment.

To achieve these objectives, a strategy-based management and operation process is in place to identify the best available capabilities, within and outside of DOE; to integrate them into a cooperative and smoothly operating organization; then to capitalize on the resulting synergy. This underlying process will allow concentrated efforts to focus on the development and implementation of technical solutions to the highest priority environmental remediation and waste management problems.

Problem Area Uncertainties

This area of investment has a number of uncertainties associated with it. First, with the lack of complete characterization, new problems can arise changing the priority of site needs. DOE records identify about 5,700 separate occurrences of soil or ground water contamination across the former weapons complex. Approximately half of the existing DOE landfills were filled with

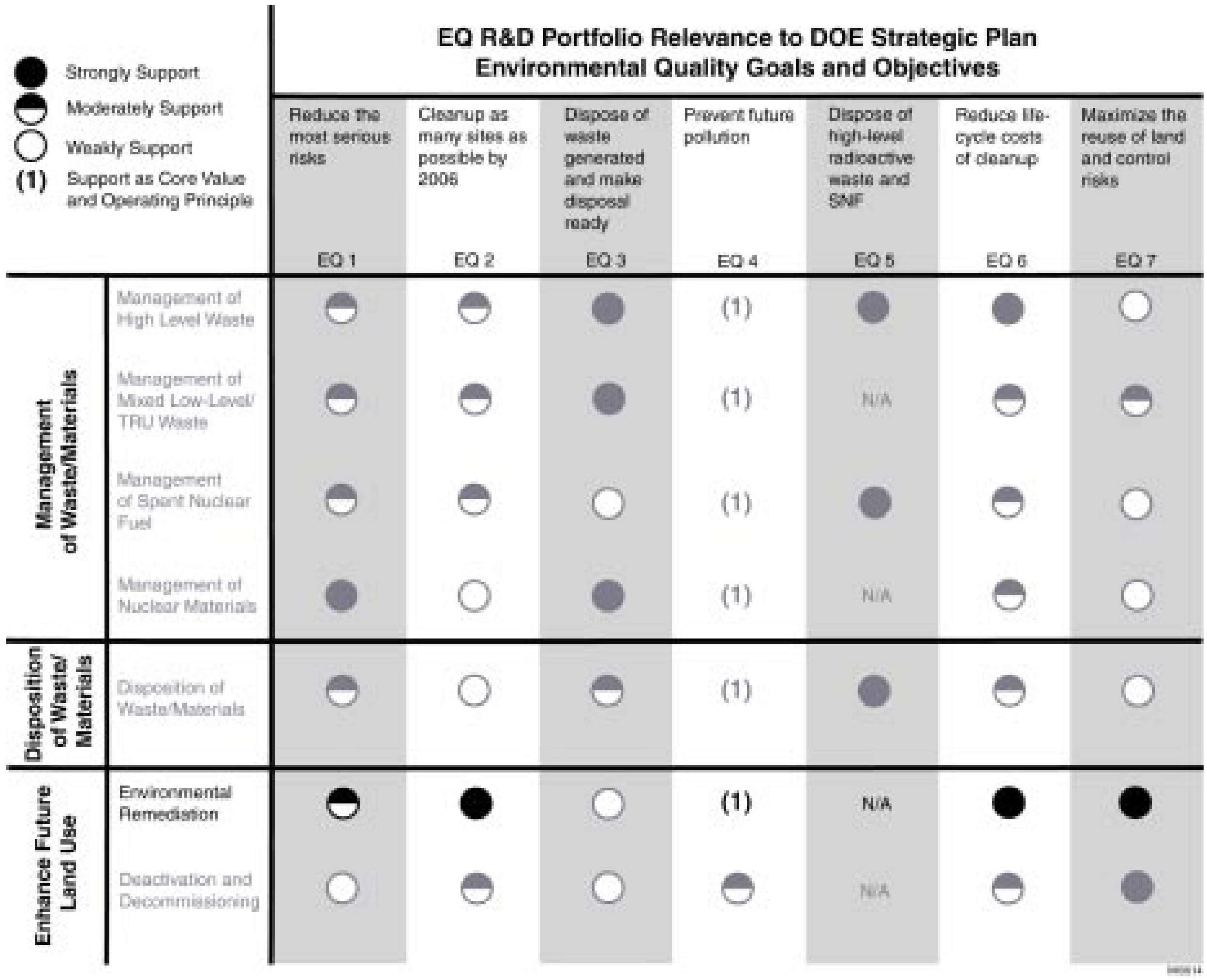


Figure 8-2. Relevance of environmental remediation R&D investments to Environmental Quality goals and objectives.

waste prior to 1970. Disposal regulations at that time allowed the commingling of various types of waste. These wastes exist in the form of solids, liquids, or sludge and have a diverse range of constituents, including polychlorinated biphenyls, heavy metals, organic solvents, and reactive compounds. As characterization activities proceed, unexpected problems will be discovered.

Second, the ultimate decision on technology use is impacted by both regulators and stakeholders. As previously discussed, existing agreements with the EPA, state agencies, and other stakeholders may constrain DOE's ability to implement maturing technologies. In addition, future regulatory changes or Records of Decision may alter the cleanup approach on a site-specific basis, requiring development of alternative remediation methods.

Third, technologies developed and demonstrated in one geologic setting may not respond well in a different setting. In addition to various types of wastes, and commingled hazardous and radioactive materials, a wide range of hydrogeologic settings at waste sites complicates the containment, removal, or treatment of subsurface contaminants. Contamination occurs in thick unsaturated zones, in high- and low-permeability soils, in aquifers, and in fractured basalt and karst bedrock.

R&D Investment Trends and Rationale

The current investment mix for R&D in support of Environmental Remediation is shown in Figure 8-3. As described previously, the current management process for the investment portfolio is expected to evolve the investment mix. Several changes are already under way:

- While general characterization investments are decreasing, investments in characterization, monitoring, modeling, and analysis of the vadose zone are increasing to address the uncertainties in determining contaminant fate and transport in this highly complex region of the subsurface.

- Investments in containment systems are also decreasing as work on barriers and other containment concepts matures. The exceptions are in the areas of stabilization of contaminants in the vadose zone and R&D for long-lived caps for landfills, where investments are increasing to better address long-term performance issues.

- In situ remediation technologies and supporting sciences receive the largest portion of investment, and the near term trend is toward increasing the investments in this area to provide deployments supporting accelerated cleanup schedules. Investments are decreasing for in situ passive flow and reactive treatment barriers, and increasing in the areas of advanced bioremediation, chemical treatment, and deep subsurface access and placement methods.

- Investments in technologies for removal and treatment are declining as less disruptive in situ alternatives are developed.

- Investments in directed science include new research efforts for vadose zone characterization and remediation and low dose radiation effects.

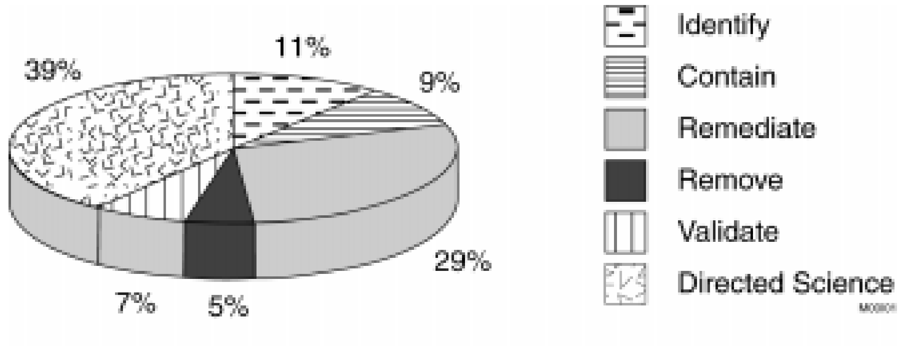


Figure 8-3. Cumulative investment in environmental remediation areas over 3 years (FY 1999–FY 2001).

Key R&D Accomplishments

The DOE has been working on the solution to key subsurface contaminant problems since 1995. In that time, the focus has matured through a better understanding of the needs of the various sites around the complex. The effectiveness of this approach can be seen in the following list of completed technologies. This list demonstrates a strong emphasis on the technologies that can identify, contain, and remove contaminants of concern. The emphasis for the future will continue to focus on these three areas, and will concentrate on *in situ* remediation and validation of the success of containment and remediation techniques.

The effectiveness of the approach can be seen in the following list of selected accomplishments:

- A significant investment in technologies for dissolved-phase organic contamination was completed in 1995. As a result, these contaminants can be more effectively remediated in aqueous environments. Examples are Remediation methods for dissolved organic plumes that are more efficient than conventional pump and treat approaches (e.g., In Well Vapor Stripping), achieving cleanup levels faster.

- Innovative drilling/subsurface access methods are being used to improve access to soil and ground water plumes (e.g., Resonant Sonic Drilling and various horizontal-drilling schemes). These approaches save money, produce less secondary waste (contaminated drill cuttings) and/or allow better access to a subsurface plume than conventionally drilled vertical wells.

- Horizontal drilling has been linked with air sparging methods and biostimulation methods to improve contact with the plume and increase mass transfer rates, thereby enhancing the rate of plume remediation.

- Improved capabilities to remove contaminants from tight, clay-like soils where baseline approaches were ineffective (e.g., LASAGNA process).

- Improved capabilities to enhance the removal rate of dense non-aqueous phase liquid (DNAPL) source zones via thermal techniques will significantly shorten remediation durations. Two methods have been provided through demonstration: Six Phase Heating Dynamic Underground Stripping/Hydrous Pyrolysis Oxidation.

- Improved capabilities to rapidly install and remove barriers to completely contain waste sites or spills (e.g., Frozen Soil Barrier). Such barriers prohibit a plume from spreading further and allow the choice of more aggressive (faster, more effective) remediation approaches.

- Ability to make accurate, single-point measurements of ground water velocity and direction via the In Situ Permeable Flow Sensor. This device minimizes the number of boreholes required for directional flow data and does not produce secondary waste (purge water) associated with baseline pump tests or slug tests.

- More sophisticated landfill capping designs that take into account operating conditions. For example, the Alternative Landfill Cover Design can more effectively isolate waste in arid climates than the clay-based Resource Conservation and Recovery Act (RCRA) Cap design, avoiding costly future cap repair jobs.

- In Situ Stabilization (ISS) of concentrated waste zones such as landfills and burial pits. ISS stabilizes and prevents further migration, or can be an interim step that permits safer excavation/removal of buried waste for ultimate disposal.

- Digface Characterization Systems is a platform-mounted series of rad detectors that can remotely survey the digface of an excavation site. This is a safer, more rapid approach to determining what waste must be excavated for ultimate re-disposal than the baseline personnel-based method.

Key R&D Issues

As the goal of final cleanup approaches reality at several DOE sites, and as the understanding of the vadose zone deepens, new and challenging technical issues have begun to emerge. These issues revolve around difficult questions: “How clean is clean”? What are appropriate goals for remediation and how does one approach a problem that may not have a finite solution? The situation becomes more complex when the needs of the stakeholders, policy makers, and regulators are considered. To ensure a satisfactory and responsive solution, these problems must be addressed in a way that weaves together the identified needs with the skills of the technical community.

Closer examination of the issues raises a series of more specific questions:

- How does EM know when remediation is complete?

- How does EM know when closures are complete and stable?

- How does EM deal with the long-term risk of remediation and closure?

- How does EM convince the stakeholders that remediation is complete? (i.e., the long-term risk to the public has been considered and deemed acceptable?)
- How does EM deal with ultimate ownership of sites when cleanup is finished?
- Is long-term DOE stewardship a viable solution for some sites?

Because these problems have become so complex, and because related issues continue to surface, the situation cannot be approached in a traditional fashion. Answering these questions requires a new and unique approach to problem solving, one that allows solutions to be achieved incrementally. An apt analogy for this approach is peeling an onion—as each layer of the problem is exposed and dealt with, a greater understanding of how to proceed to the next step is obtained.

Clearly, the Department must respond with a comprehensive, integrated program that involves thoroughly understanding all of the elements of the problem, establishing the desired objectives and time frames, and then developing the methods to meet these objectives. The development and implementation of a viable program will not be accomplished in the short term. Many of the larger problems facing the complex will require tens of years to institute a remediation or closure program with the proper goals or end states. Effectively dealing with a problem set of this magnitude, will require that the current level of EM resources must be maintained, if not increased, and allocation of these resources must shift over time to focus on these longer term challenges.

There are several key issues that are beyond the current planning horizon, which will drive the need for longer-term research and development investment in the environmental remediation area. Some of these issues are:

- Definition of the contaminant inventory in the vadose zone across the DOE complex and prediction of the ultimate fate of these contaminants.
- Determination of the risk to people and the ecosystem associated with the residual contaminants left at the end of planned cleanup activities.
- Long-term stewardship of residual source terms in burial ground and waste tank closures.
- Development of a strong technical basis for decisions made for ultimate land-use planning.

Problem Area R&D Program

Budget: FY99-$77.5M, FY00-$58.9M, FY01-$58.8M

Program Description

In order to address the widespread and diverse problems of environmental remediation, investments will span the full range of technology development. The activities will address questions ranging from contaminant transport, soil interaction, and sorption to underground substrates. Innovative technologies are required to locate deep contamination. The program addresses all aspects of the location, characterization and remediation of subsurface contamination.

The five major environmental remediation program activity areas are:

- Identify methods to accurately locate and characterize subsurface contaminants.
- Develop in situ techniques that contain and/or stabilize leaks and buried wastes.
- Develop in situ processes that treat or destroy mobile contaminants (remediate).
- Develop technologies that remove and treat contaminants not treatable in situ.
- Develop methods that validate the performance of treatment and containment systems for regulators and stakeholders.

Identify

Budget: FY99-$9.4M, FY00-$6.1M, FY01-$6.7M

Description. It is imperative that subsurface contamination be accurately located and characterized to select the most cost-effective containment or remediation systems. DOE Sites need better technologies to predict the long-term movement and fate of these contaminants, especially in support of remediation efforts.

Objective. The objective is to provide a suite of characterization tools from which end users can select and implement those most appropriate to define their contamination problems. Three major goals have been identified for this program area:

- Locate DNAPL source zones in fractured rock and unconsolidated media.
- Broaden understanding of the fate and transport of contaminants in the vadose zone.
- Broad understanding of the fate and transport of contaminants in the saturated zone.

Approach and Activities. The approach to achieving the above objectives is defined by the following development areas:

- Improved analytical tools.

- Improved in situ monitoring devices that eliminate the need to retrieve and transport samples.
- Improved understanding of permeability patterns in order to locate contaminants, including DNAPLs, in fractured and karstic rocks at depth with a minimum of drilling.
- Improved understanding of contaminant inventory, distribution, and movement in the vadose zone.
- Improved tools to better predict ground-water flow, transport, or the effects of pumping or reinjection scenarios to more effectively target remediation technologies.

R&D activities will include deployment of Laser Induced Fluorescence, Alcohol Microinjection/Extraction, and Hydrophobic Flexible Membrane technologies at the Savannah River Site to accurately locate and quantify subsurface contamination. All of these technologies provide indications of DNAPL chemicals, but require conventional or direct-push drilling methods for emplacement.

There are additional plans to deploy at SRS, the anomaly-versus-offset (AVO) Seismic Reflection technology for the non-invasive determination location/distribution of free phase DNAPLs.

Contain

Budget: FY99-$6.2M, FY00-$5.6M, FY01-$5.2M

Description. A key factor in the DOE environmental remediation program is the capability to envelop or stabilize the current remediation problems and either minimize or prevent their growth through migration. Containment technologies are crucial to successfully keeping existing contamination problems at their current level. Activity in this area involves the demonstration and preparation for deployment of a number of containment technologies designed to function as an intermediate containment solution or as a permanent remediation solution.

Objective. The three main goals to achieve containment are:

- Contain and stabilize buried waste.
- Stabilize waste in situ.
- Protect buried sites for the long-term through capping systems.

Approach and Activities. Develop in situ techniques that contain and/or stabilize leaks and buried wastes, emphasizing specifically:

- Subsurface barrier systems in the vadose zone.
- Stabilization of contaminants in the vadose zone.

- Long-lived caps.

Activities include demonstration of a Viscous Liquid Barrier at a site hotspot at (Brookhaven National Laboratory [BNL]). These barriers are a means of containing or stabilizing leaks and buried waste hotspots in situ. A Subsurface Containment System Deployment for conditions greater than 100 ft will also be attempted at Oak Ridge National Lab. In situ vitrification, utilizing a novel approach that begins below the targeted waste and melts upward, will be demonstrated at Los Alamos National Lab.

Remediate

Budget: FY99-$18.4M, FY00-$21.0M, FY01-$17.8M

Description. The capability to destroy contaminants in situ is a preferred method of remediation because it reduces the risk to the environment and to the public and is typically less expensive. These techniques produce much lower levels of secondary waste, thus reducing future waste legacies. Gaining access to contaminants in the diverse geologic settings across the Complex is the greatest challenge to in situ destruction. DNAPL concentrations below the water table, if not destroyed, will continue to contaminate the aquifer for years. Promising technologies to define and treat these areas of high concentration levels in complex hydrogeologic conditions are being demonstrated.

Objectives. The five major goals for remediation technology development are:

- Establish reactive barriers that are capable of destroying mobile contaminants in the saturated zone.
- Effectively bioremediate contaminants in the subsurface to destroy or stabilize.
- Chemically treat contaminants in the vadose zone to destroy or stabilize.
- Chemically treat contaminants in the saturated zone to destroy or stabilize.
- Develop deep access techniques for the delivery of treatment technologies.

Approach and Activities. Develop a series of in situ processes that treat or destroy mobile contaminants. The series includes:

In Situ Passive Flow, Reactive Treatment Barriers to fill technology gaps and provide for the effective remediation of dispersed-contaminant plumes. Remediation of these dispersed plumes by pump and treat is inefficient, expensive, and produces significant secondary waste. In some hydrogeologic settings, it is not practical to install pumping systems. These in situ passive flow, reactive treatment barriers trap or destroy radionuclide, metal, and chlorocarbon contaminants moving in the ground water.

DOE plans to complete the performance verification of a Reactive Barrier (Funnel and Gate), installed at Rocky Flats SMWU 059, to treat or destroy mobile contaminants in situ. Additional barriers have been installed at 3 Rocky Flats SMWUs in FY2000. A Reactive Barrier (Funnel and Gate) will be demonstrated at Oak Ridge Y-12/S-3 Ponds and an Iron

Treatment Wall will be deployed at the Kansas City Plant “Northeast Area” Plume. An additional outyear deployment is planned at LLNL Site 300. A permeable reactive treatment (PERT) wall will also be deployed at the Grand Junction Office, Monticello, Utah, Uranium Mill Tailings Remedial Action (UMTRA) plume.

Advanced Bioremediation and Enhanced Natural Attenuation technology development will allow for the remediation of low to moderate concentrations of organic solvents that are common in soil, ground water, and leaking buried waste at many DOE sites. Areas of emphasis include microbial attacks on fuels or solvents, microbially enhanced barriers, and the application of vascular plants to remove contaminants from soil or ground water.

Treatment of Vadose Zone Using Chemical Treatment technologies will provide effective methods to remediate metals, rads, explosive residues, DNAPLs, and solvents in the vadose zone. These are less costly and produce minimal secondary waste compared to conventional remediation, such as excavation, treatment, and the disposal of contaminated soil. Development areas include in situ methods to destroy, immobilize, remove, stabilize, or otherwise mitigate dispersed contaminants in the vadose zone. The contaminants include metals, radionuclides (fission and activation products, transuranics), explosive residues, DNAPLs, and other solvents.

An In Situ (Gaseous Remediation (of Chronate) will be demonstrated.

Chemical Treatment of the Saturated Zone will fill technology gaps and replace traditional recovery-type remediation technologies that are too inefficient and time consuming to support the baseline cleanup goals. Technologies to destroy highly concentrated contaminant source terms are needed to increase remediation rates and reduce the term of remediation. The contaminants to be addressed include metals, radionuclides (fission and activation products, transuranics, tritium), explosive residues, DNAPLs, and other solvents.

An In Situ Soil Flushing system for the mobilization and extraction of M&R (Sr90 emphasis) will be demonstrated at Hanford.

Hydrous Pyrolysis treatment has been demonstrated at Portsmouth, Ohio, a DOE site contaminated with TCE and other DNAPLs and the system will be deployed at Savannah River in FY00.

Electro-osmosis (Lasagna™) will be deployed at Paducah, KY, and a surfactant enhanced aquifer remediation will be deployed at an interagency commercial cleanup site in New Hampshire. In addition, an In situ Chemical Oxidation of DNAPLs will be deployed at Oak Ridge. Off Site in Well Air Stripping, NOVocs™ will be demonstrated at BNL for offsite DNAPLs.

Residual DNAPLs in Oxidation (Fenton’s reagent or Potassium Permanganate) treatment zones will be evaluated and decomposed.

Deep Subsurface Access and Placement Methods investments will fill technology gaps and provide the capability to provide access, sampling, and delivery methods to place characterization and treatment technologies in DOE's deep plumes. These plumes will be the most costly to remediate due to contaminant depth and geologic complexity. Areas of emphasis include improved drilling technology for sampling, delivery of treatment chemicals, or contaminant removal methods that minimize Investigation-Derived Waste (IDW) and can be used at great depth.

Deployments in this area include deep jet grouting at a DOE site to be determined, which will enable deep Cr(VI) treatment.

Remove

Budget: FY99-$3.3M, FY00-$4.3M, FY01-$1.9M

Description. Effective removal technologies are required when it is deemed necessary to remove landfill wastes to alleviate future threats. Objectives for these technologies include contamination-control measures, waste segregation and minimization, and excavation process improvements. Removal technologies must also take into account increased worker-safety concerns from the concentrated waste forms encountered. Removal technologies for dispersed contaminants in ground water and soil are necessary for those metals and radionuclides that are nondegradable. In some settings, it may be more efficient to remove DNAPLs than to destroy them *in situ*. Removal technologies that rely on solubilizing agents or surfactants will require recovery or regeneration in order to minimize generation of secondary waste.

Objectives. The goal of removal is to eliminate hot spots from the subsurface.

Approach and Activities. Develop technologies that remove and treat contaminants that are not treatable in situ. The approach focuses on Hot Spot Removal from Landfills and Subsurface Sources through investments to fill technology gaps and provide the capability to effectively characterize and remove highly radioactive, explosive, and pyrophoric wastes which pose an unacceptable risks to remediation workers during excavation. Technologies that allow for the on-site characterization of waste to be exhumed and the remote retrieval of high-risk waste will reduce the risk to remediation workers.

DOE plans to deploy Dig Face Characterization (Warthog) at FEMP to remove hot spots not amenable to in situ treatment. Segmented Gate Soil Processing deployed at Sandia National Laboratories (SNL), Los Alamos, INEEL, NTS, and with FEMP in 2001.

Validate

Budget: FY99-$3.0M, FY00-$4.3M, FY01-$5.6

Description. Innovative subsurface barriers and remediation technologies are currently being developed and tested for the control and remediation of waste units across the DOE complex. End users and regulators need confirmation that these systems and methods provide the long-term solution to the contamination problems they are intended to solve. The DOE is developing and testing monitoring and analytical techniques to determine barrier integrity and the effectiveness of remediation in the years following their implementation.

Objectives. The goal of validation is to demonstrate and assure the long-term performance of barriers and other solutions.

Approach and Activities. The approach is to develop methods that validate the performance of treatment and containment systems for regulators and stakeholders. The focus is on *In Situ Passive Flow, Reactive Treatment Barriers* to provide methods to validate the integrity of containment systems, predict long-term performance to meet stakeholder and regulatory concerns, and thereby enable their use as a remedy. Regulatory agencies require technology system validation and verification prior to use. Development areas include methods to verify and validate the long-term performance of containment, stabilization, or treatment systems. This is especially important because data must be adequate to demonstrate that new containment systems are capable of meeting their design lifetimes. This activity will be coordinated with the EPA SITE Program and Department of Defense (DOD) programs.

DOE, working with CMST, plans to deploy the Evapotranspiration Cover/Integrated Fiber-Optic Performance Monitoring System at Albuquerque (SNL) to validate and verify system performance to regulators and stakeholders.

Directed Science

Budget: FY99-$37.3M, FY00-$17.6M, FY01-$21.6M

Research can assist the Department with solving environmental problems associated with hazardous and radioactive contaminants in soil and groundwater that exist throughout the DOE complex, including radionuclides, heavy metals, and dense, nonaqueous phase liquids. Currently, the research is focused on the following areas:

- Characterization and location of contamination in soil and groundwater.
- Removal/remediation of contaminants in groundwater and soils.
- Separations of radionuclides from hazardous contaminants for treatment and disposal.
- Prediction of future contamination and migration of contaminants.
- Improved understanding of human health and environmental risks.

Since 1998, over 100 directed research projects have been funded, including over $34 million in research to address issues related to health, ecology and risk, and 31 new projects to specifically study contaminants and remediation of the vadose zone. This research portfolio is in the scientific areas of actinide chemistry, analytical chemistry and instrumentation, biogeochemistry, engineering science, geochemistry, geophysics, health science, hydrogeology, inorganic chemistry, microbial science, plant science, and separations chemistry.

- *Actinide Chemistry:* Research in this area is focused on providing a better understanding of the speciation, characterization, and migration of plutonium in soils and surface and ground waters. For example, one research project seeks to experimentally derive a thermodynamic model of plutonium/actinide complexation under chemically harsh conditions relevant to high level wastes that will describe the speciation of the actinides and plutonium in such systems.

- *Analytical Chemistry and Instrumentation:* Research in this area is to develop protocols for quantitative analysis of tank waste materials based upon turnable infrared ultra pulsed lasers. Other areas of research address biomedical instrumentation, laser ablation techniques, and sensors and techniques. Develop or improve instrumentation and techniques to assist in characterizing the contamination at DOE sites. Additional research ranges from the development of a better understanding of genetic and metabolic potentials in in situ bioremediation to improvement in characterization techniques for chemical, physical, or radiological contaminates using microsensors or laser ablation.

- *Biogeochemistry:* This research includes investigations of reduction and immobilization properties of metals, radionuclides, and other contaminates in various media. One project will probe fundamental scientific issues regarding microbial process with the potential for decontamination corroding metal surfaces. Other projects include improved understanding and predictive capability of the mechanisms that allow metal-reducing bacteria to be effective in the bioremediation of subsurface environments contaminated with toxic metals and radionuclides; microbiological and geochemical controls on carbonate mineral precipitation reactions that are caused by bacterial reduction of Fe oxides, and solid phase capture of strontium and other metal/radionuclide contaminants.

- *Engineering Science:* This research provides knowledge in the areas of bioengineering and bubble mechanics, high level waste, and sonification. Research is being conducted to investigate the in situ degradation of semivolatile organic compounds (SVOCs), with the goal of partial degradation of the more recalcitrant SVOCs, in order to convert them into compounds that are more amenable to both vapor stripping and biological treatment.

- *Geochemistry:* Research includes studies in colloidal chemistry and transport and sorption/desorption. There are twenty projects being funded in the geochemistry area, the following is a summary of a few of those projects: use of isotopic ratio measurements on aquifer groundwaters and vadose zone gas for improving remediation strategies and increasing the efficiency of ongoing remediation activities; interactions between contaminants and gas-water interfaces, with emphasis on sorption behavior of mixed contaminant systems; kinetics and mechanism(s) of heavy metal retention/release by soil mineral colloids as affected by inorganic anion. The colloids will be characterized in terms of surface area, surface charge and surface site density. They will be used to study the effects of pH, phosphate rate, and temperature on metals retention/release; and, at Hanford a project is investigating the geochemistry of cesium adsorption under conditions relevant to HLW tank releases. The goal is to develop field relevant knowledge to improve transport calculations of cesium beneath the tank farms and provide needed insights for long term decision making pertaining to performance/risk assessment and site remediation.

- *Geophysics:* This research will improve the understanding of subsurface imaging. Research is focused on developing or improving methods for subsurface imaging that will improve characterization and monitoring in the shallow subsurface, the vadose, and plumes. The scientific knowledge will advance the understanding of movement of contaminates in the subsurface media.

- *Health Science:* Research is focused on molecular, structural, and genomic science. Projects include protein engineering of existing enzymes and the "creation" of new enzymes (catalytic antibodies) with enhanced dechlorination capability for a wide variety of chlorinated organic pollutants, and molecular and catalytic properties of enzymes that have been chemically modified so that they are soluble and catalytically active in pure organic solvents.

- *Hydrogeology:* This research addresses scientific issues related to the areas of dense non-aqueous phase liquid (DNAPL) dynamics, fluid-flow and colloidal dynamics, and instrumentation and modeling. The research is critical to obtaining a better understanding in such areas as migration, entrapment, transport, and characterization of contaminants in the DNAPLs. A total of 23 projects have been funded in hydrogeology.

- *Inorganic Chemistry:* Investments in this area are focused on multiphase/gaseous chemistry and solid/solution chemistry. One project is pursuing investigations of the interactions of the relevant chlorinated solvents, trace elements, and trace element-containing compounds with single- and poly-crystalline Fe surfaces. This work will provide a fundamental physical and chemical understanding of these interactions, which is critical for the development of cleanup techniques and procedures.

- *Microbial Science:* Investments in microbial science provides knowledge on biodegradation and biotransformation, microbial genetics and instrumentation, and microbial transport. Currently, there are eight research projects funded in this area. Projects include attachment/detachment dynamics of anaerobic bacteria in heterogeneous porous media under growth and growth-limited conditions; environmental conditions and mechanisms by which anaerobic bacteria partition between aqueous and solid phases; and identify the stress-inducible gene from two soil bacteria. The resulting fundamental information on stress-responsive genes will provide an increased knowledge of stress responses of indigenous microbes at contaminated sites as well as molecular probes for monitoring performance and effectiveness of bioremediation.

- *Plant Science:* Research in this discipline addresses plant genetics and plant membrane transport. The research will improve the understanding of phytoremedation in cleanup of metals and transport of metals in plants. A number of terrestrial plants are known to naturally accumulate high levels of metals in their shoots, these plants are known as metal-hyperaccumulators. Projects include genetic traits determination for metal-hyperaccumulation, with a long-term objective to rationally design and generate plants ideally suited for phytoremediation using this unique genetic material; and testing the ability of several plant clones to take up and transform various forms of chlorinated hydrocarbons (CHCs). Previous lab experiments have shown that fast-growing and deep-rooted hybrid poplar take up and transpire trichloroethylene at a high rate, and that significant amounts of TCE are oxidized to carbon dioxide.

- *Separations Chemistry:* This research addresses studies related to catalyst chemistry and waste treatment and ligand design and ion exchange. One example of the investments being made in separations chemistry is a project that focuses on the development and demonstration of a robust ceramic-supported polymer (CSP) membranes for organic-aqueous and organic-organic separations. The CSP membranes will be fabricated by modifying the pore surface of a ceramic support membrane via a graft polymerization process to form a thin layer of terminally anchored chains covalently bonded to the membrane pore surface. The CSP membranes can also be fabricated as hybrid membranes for simultaneous ultrafiltration and metal ion removal.

The next three research areas are applicable to several waste types, including waste types discussed in other chapters. The research is described here due to its high degree of applicability to the waste types discussed in this chapter.

- *Chemistry of Environmental Surfaces:* Identify and understand surface chemistry processes that occur on the surfaces of materials found in the environment such as soils, vegetation, and construction materials (such as concrete or steel) that are of importance to DOE EM and its environmental cleanup activities. Examples of application range from understanding the interactions of contaminants on geological surfaces as they move through geological media to understanding binding of contaminant species on the surfaces of buildings slated to be decontaminated and decommissioned. Through this identification and understanding the foundation for development of new cleanup methods will be established. Research in this are will consist of five activities.

  – Advanced Strategies for Probing Structure and Reactivity at the Top Monolayer. Identify novel surface structures and reactions through identification of innovative surface analytical strategies that will be used to identify metal-ligand structures existing on the surface of inorganic materials (such as minerals). The strategy will involve the development of new chemical, mass, and optical spectroscopy approaches. These approaches will be designed to overcome current experimental problems associated with strong adsorption, irregular surface morphology, and lack of sensitivity for surface species.

  – Biochemical and Geochemical Reactions on Environmental Surfaces. Develop activity is to develop a detailed understanding of bio- and geochemical surface reactivity for selected systems. Mineral surfaces and their interactions with contaminant species will be examined to gain additional insight into the role that microorganisms (or their chemical byproducts) play in the transport and/or degradation of the contaminants. Of particular interest from a geochemical perspective is the area of geochemical catalytic degradation of chemical contaminants.

  - Reactive Transport in Variably Saturated Heterogeneous Media. Develop, parameterize, and test a comprehensive modeling framework for the movement and transformation of reactive constituents such as actinides, radionuclides, and other environmental contaminants is physically, geochemically, and biologically heterogeneous variably saturated subsurface media.

  - Transport Phenomena in Geologic Porous Media. Investigate the inter-relationships and activities of attached and detached microbial communities in porous media and how these relation ships and activities may be affected by perturbation by contaminants. A particular focus will be on the area of relationships between biological and physical heterogeneities.

  - Vadose Zone. Integration of field vadose zone measurements and inverse modeling approaches to define more realistic representations of vadose zone heterogeneity that include estimates of property uncertainties and allow the design of improved vadose zone characterization strategies. This task will include a significant field component, as detailed field measurements will be required.

  - Environmental Management Science Program Transition. Provides transition collaborations and funding for two EMSP projects, related to under surface geophysical measurements, that have completed their EMSP funding cycle and are of interest to the Subsurface Contaminants Focus Area.

  - Surface Speciation of Radionuclides in Environmental Media. Study the effects of various surfaces of environmentally significant media in the subsurface on the oxidation states and speciation of radionuclides of concern. Oxidation state and speciation are important parameters in the fate and transport of radionuclides and are particularly complex in the transuranics.

- *Characterization science.* Characterization methods are critical in waste remediation, handling, and processing activities. The program focuses and five areas one of which, "Integrated Instruments for In Situ Chemical Measurements", has broad application to Environmental Remediation.

  - Integrated Instruments for In Situ Chemical Measurements. The ability to fabricate low-cost, integrated sensor packages, using techniques currently applied to integrated circuit fabrication, will lead to a wide variety of inexpensive chemical and physical property sensors. Using this information and additional technical assessment, a research effort will be initiated to begin development of the underlying and enabling techniques for integrated sensors.

- *Long-Term Environmental Stewardship*. Focuses on the identification and modeling of ecological health and landscape indicators that will be useful in the assessment and accomplishment of long-term stewardship for DOE facilities.

Risk Program - Although of a somewhat different nature than the preceding directed research, there is scientific uncertainty about the levels of risk to human health and the environment at the end stages of the DOE cleanup effort. Accurate risk analyses require thorough knowledge of contaminant characteristics, basic ecological processes and principles, rates at which contaminants move through ecosystems, and health and ecological effects. In particular, better knowledge of radionuclide and toxic chemical transport dynamics and the potential effects of long-term exposure to low levels of radionuclides, in combination with other contaminants, is essential. Research is required to improve understanding of threatened and damaged ecosystems and processes to restore the viability and quality of these ecosystems.

Between 1998 and 2000, the Department has funded approximately $22 million in research to address issues related to health, ecology, and risk. Health, ecology, and risk is a crosscutting problem area; therefore, the research investment will impact cleanup work across the DOE complex.

Research currently being funded by the Department is addressing the issues or problems in the following areas:

- Identification of biological pathways and effects of contaminants in order to determine levels of risk.
- Identification of methods for determining the human health toxicity of contaminants.
- Evaluation of low dose effects from radiation and evaluation of the toxic effects of radioisotope/chemical synergisms on humans and biota.
- Improved detection of hazardous conditions and development of protective equipment.
- Evaluation of methods of assessing worker exposure, including safety risks during remediation activities.
- Understanding of soil properties and microorganism ecology to determine uptake of contaminants.
- Understanding how remediation activities affecting surface water, groundwater, ecological systems, and emissions generated by remediation activities impact the environment.
- Development of comprehensive long-term models of ecological systems.
- Development of methods for relating cleanup levels to environmental risk.
- Development of a credible risk assessment tool to evaluate residual and cumulative risk.
- Developing scientific foundations to understand the observed drop in efficiency over time in pump and treat operations.

- Merging and validation of air particulate models that predict future exposures.
- Validation of biomarkers by linking them to DOE Worker data bases.

The results are expected to assist the Department in protecting the public, workers and the environment and in the decision making process in such areas as land use issues and end states.

Low Dose Radiation Research Program - In 1999, a joint research program was initiated by the Office of Science and the Office of Environmental Management to study the health effects of low doses of radiation. The Low Dose Radiation Research Program supports research to determine if low dose and low dose-rate radiation presents a health risk to people that is the same as or greater than the health risk resulting from the oxidative by-products of normal physiological processes. This information is a key determinant in decisions that are made to protect people from adverse health risks from exposure to radiation. The research program builds on advances in modern molecular biology and instrumentation, not available during the previous 50 years of radiation biology research, to address the effects of very low-levels of exposure to ionizing radiation. It will concentrate on understanding the relationships that exist between normal endogenous processes that deal with oxidative damage and processes responsible for the detection and repair of low-levels of radiation-induced damage. Research will focus on understanding cellular processes responsible for recognizing and repairing normal oxidative damage and radiation-induced damage. If the damage and repair induced by low dose radiation is the same as for normal oxidative damage, it is possible that there are thresholds of damage that the body can handle. In contrast, if the damage from ionizing radiation is different from normal oxidative damage, then its repair, and the hazard associated with it, may be unique. To understand the relationship between normal oxidative damage and radiation-induced damage, studies will be conducted at very low doses and dose-rates and the perturbation of the normal physiological processes will be characterized at all levels of biological organization—from genes to cells to tissues to organisms.

A total of 44 awards were made in the five interrelated areas listed below. Research will be used to development a better scientific basis to understand exposure of risk to humans from low dose radiation that can be used to achieve acceptable levels of human health protection at the lowest possible cost.

Research is supported in five interrelated areas:

- Low dose radiation vs. endogenous oxidative damage.
- Understanding biological responses to radiation and endogenous damage.
- Thresholds for low dose radiation.
- Genetic factors that affect individual susceptibility to low dose radiation.
- Communication of research results.

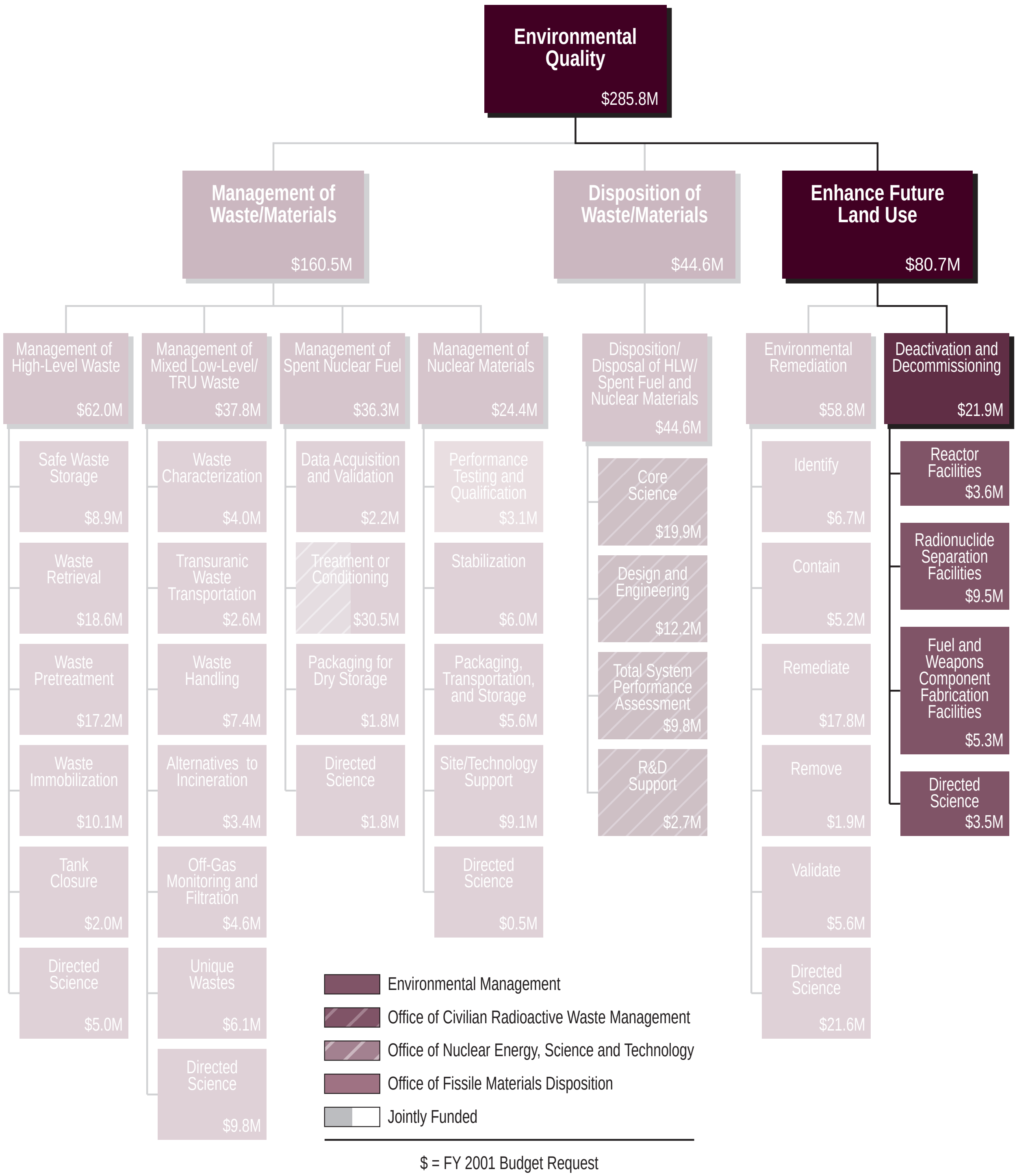
Budget Summary Table

(Dollars in thousands)

Research Areas	FY 1999 Appropriated	FY 2000 Request	FY 2001 Request
Identify	9,418	6,085	6,717
Contain	6,151	5,603	5,178
Remediate	18,364	21,027	17,843
Remove	3,261	4,306	1,862
Validate	2,988	4,289	5,603
Directed Science	37,344	17,591	21,607
Total	**77,526**	**58,901**	**58,810**

Chapter 9

Deactivation and Decommissioning



Chapter 9

Deactivation and Decommissioning

Table of Contents

Overview

Definition of Problem Area

DOE constructed over 20,000 facilities to support nuclear weapons production and other activities. Many of these facilities are contaminated with radioactive materials, hazardous chemicals, asbestos, and lead (including lead paint), have exceeded their design life and no longer serve a mission for the DOE. The potential for release of radioactive and hazardous materials to the environment and local communities and the risk of industrial safety accidents due to the deterioration of these old facilities requires monitoring and maintenance. DOE plans to deactivate and decommission such facilities to reduce these risks and associated costs. Four major classes of facilities require Deactivation and Decommissioning: (1) Reactor Facilities, (2) Radionuclide Separation Facilities, (3) Fuel and Weapons Component Fabrication Facilities, and (4) Laboratory Facilities.

Facility D&D generally follows a sequence of activities which allows for safe *deactivation* and *decommissioning* of facilities while significantly reducing the risk to workers, the public, and the environment. The physical process for dispositioning the Department's surplus facilities includes:

Deactivation. Activities to reduce the physical risks and hazards at these facilities, to decrease costs associated with facility mortgage, and make these facilities available for potential reuse or eventual decommissioning. This includes planning, removal of surplus materials, chemicals, supplies, classified equipment and documents, and stabilization of radioactive contamination. It also includes recycling, minimization, treatment, storage and disposal of all secondary wastes generated during deactivation.

Decommissioning. Activities associated with decontamination, demolition, and final disposition of the facility and the equipment contained within. This includes developing regulatory and project management documents, characterization and engineering work plans to establish cleanup criteria, characterization reports, decontamination and dismantlement, disposing of contaminated waste, verifying project completion, and issuing completion reports.

These actions are founded on assessment phases that analyze present conditions, end state requirements, and options for achieving closure.

Based on the FY1999 baseline cleanup data available through the web-based Integrated Planning, Accountability and Budgeting System, the DOE-EM mortgage for D&D services is estimated at a life-cycle cost of $12.5 billion. Figure 9-1 shows the EM D&D pre-FY2007 and post-FY 2006 life-cycle costs for the major DOE sites.

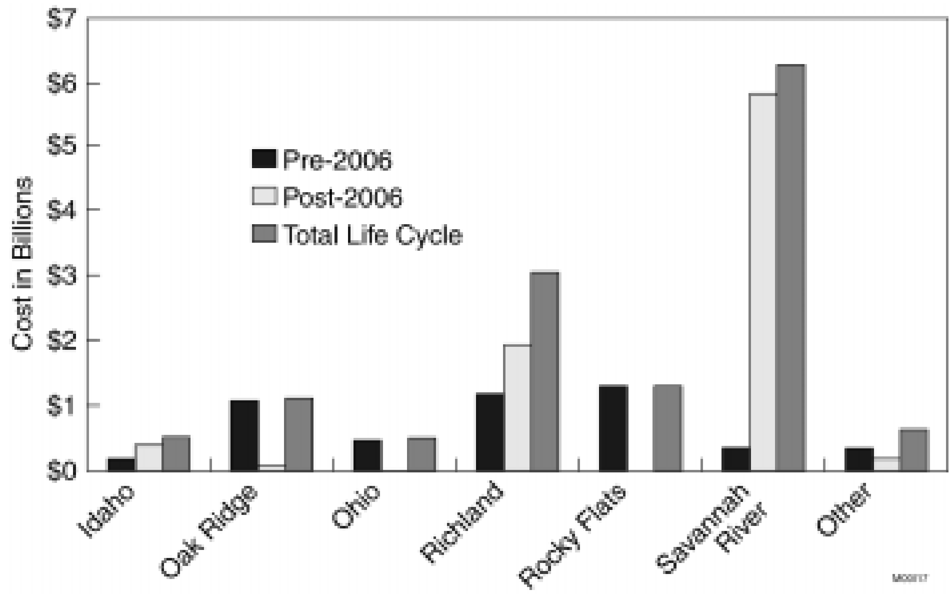


Figure 9-1. Through 2006, Post-2006, and Life Cycle costs for managing D&D costs.

EM typically performs decommissioning under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as a "non-time-critical removal action." In fact, there are few regulatory compliance agreements at DOE sites that specify D&D activities. Most sites Federal Facility Agreements deal with legacy waste (e.g., high-level waste [HLW]; transuranic [TRU]; mixed low-level waste [MLLW]; etc.) and contaminated soil and groundwater problems, not with contaminated buildings. Sites with compliance drivers include Fernald, Mound, Rocky Flats, and portions of Hanford, the Idaho National Engineering and Environmental Laboratory (INEEL), Oak Ridge, and Savannah River. Three sites are designated as EM Closure Sites (Fernald, Mound, and Rocky Flats) with site closure nominally planned by the end of FY2006 (provided that sufficient annual funding is available). Given current planned funding scenarios, Mound is expected to close by the end of FY2003, and Fernald and Rocky Flats by the end of FY2006.

In the cleanup baseline data, site problem holders for facility D&D activities have identified 180 FY1999 active needs (163 technical and 17 basic science) that must be met to accomplish the current baselines. As more close out activities are identified and planned it is anticipated that the list of technology needs will expand and, despite efforts to anticipate every requirement, surprises are bound to occur.

The current set of major problem categories include:

- Remote characterization, decontamination and dismantlement technologies for tritium contaminated facilities and highly radioactive environments.

- Underwater characterization, video inspections, sample collection, radiological surveys, sizing, handling, packaging and decontamination problems associated with fuel storage pools and associated facilities.

- Remote characterization of chemical reprocessing facilities (canyons) to assess and describe possible end states and develop an appropriate disposition path.

- Methodologies capable of characterizing and detecting to release limits for treatment and recycle of contaminated scrap metal.

- Remote and/or robotic technologies for D&D activities on hot cells and gloveboxes, which are contaminated with high-levels of radioactivity and are often confined spaces.

- Technological problems in the D&D of graphite reactors in control and containment of aerosols and airborne contamination (graphite particles) during dismantlement operations and in identifying the quantity and location of radioactive contamination.

- Evaluation of the option of disposing of chemical reprocessing facilities (canyons) by removing all contaminants above the transuranic (TRU) threshold, filling the structure with low-level waste (LLW), and entombing the canyon as a permanent LLW disposal facility.

National Context/Drivers and Federal Role

DOE is only one of the two major owners of radiologically contaminated facilities facing D&D; commercial nuclear utilities are the other major owner. There are 442 commercial nuclear power plants worldwide, of which 109 are located in the U.S. Several of these facilities are currently in or slated for D&D. Due to the deregulation of the electric power industry and the number of facilities approaching their expected operational life (NRC nuclear power plant licenses are for 40 years), many more are expected to enter D&D in the next ten years. The current estimated D&D cost for one such nuclear power plant is $400 million-$500 million (in current year dollars). This includes the cost of temporary storage of spent fuel until the DOE geological repository opens sometime in the 2010-2016 period. From this data, it is clear that the commercial nuclear sector must deal with an even greater total D&D cost than DOE. Collectively, these are expected to accelerate D&D activities in the commercial sector over the next 10 to 15 years. An opportunity exists, therefore, to leverage scarce DOE and nuclear utility resources to provide solutions to common technological problems. Toward this end the Department negotiated and signed a Memorandum of Understanding (MOU) with EPRI and major commercial nuclear utility companies agreeing to collaborative research, development and demonstration (RD&D) efforts. This MOU establishes a mechanism to facilitate the exchange of best business practices and lessons learned, and to plan/manage a leveraged RD&D program which meets the D&D technical needs of both DOE and the commercial nuclear utilities. The DOE expects to gradually transition a portion of its program to support this joint effort with the utilities.

Linkage to DOE Strategic Goals and Objectives

The D&D strategies and activities support and impact the Environmental Quality strategic objectives at the levels indicated in Figure 9-2.

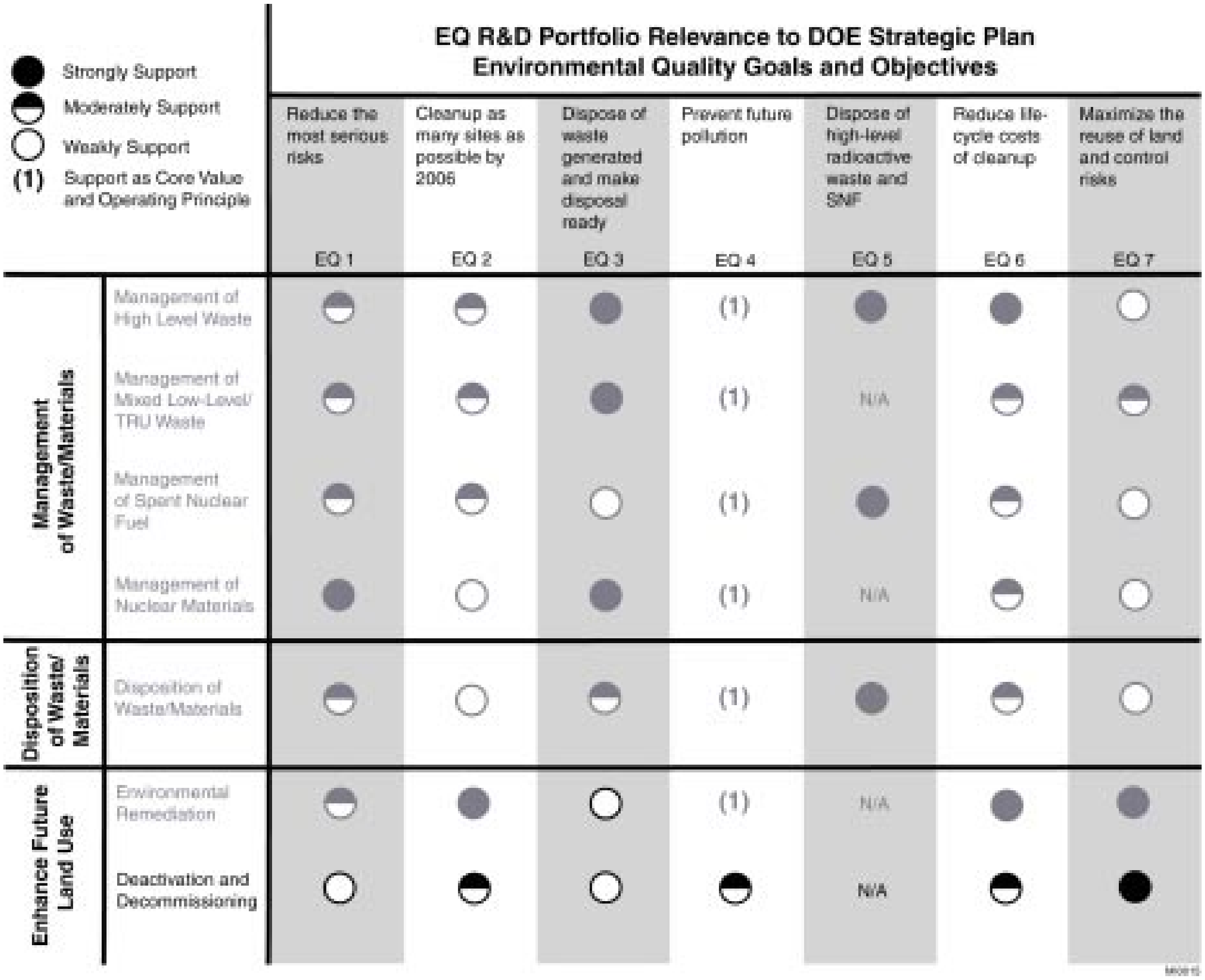


Figure 9-2. Relevance of D&D R&D investments to Environmental Quality goals and objectives.

Table 9-1. Life-cycle cost for DOE-EM Facility D&D (in millions of constant 1999 dollars)

	FY1999-2006	FY2007-2070	FY1999-2070
Deactivation	1,958	7,396	9,354
Decommissioning	2,609	580	3,190

The DDFA vision is to reduce the EM's overall life-cycle cost/mortgage for D&D of $12.5 billion by 40% to $7.4 billion. Based on validated cost reductions of 20-40% for improved technologies demonstrated at Large Scale Demonstration and Deployment Projects and their subsequent deployments, the DDFA believes the EM's near-term (through FY06) D&D mortgage of $4.6 billion can be reduced by 25% for a net reduction of $1.1 billion. Furthermore, based on results achieved by best-in-class R&D organizations, investments in basic science can be expected to result in returns-on-investment (ROI) of 20-100. Though investments in basic science tend to be high payoff, they are also high risk. Thus DDFA fully recognizes that some basic science endeavors will result in zero ROI. It is therefore not unreasonable to assume an average cost reduction of 50%, resulting in a $4 billion cost/mortgage reduction for post-2006 D&D projects.

Considerable D&D expertise also resides in the commercial nuclear sector within both the nuclear utilities and the commercial D&D contractor firms. EM has worked together with the commercial nuclear industry to exchange lessons learned and best practices and to develop a leveraged research, development and deployment program that meets D&D technical needs for both DOE and the commercial sector. EM’s D&D technology program strategy is to quickly access and demonstrate/validate the many commercially available D&D technologies worldwide, which are not currently being used within the DOE Weapons Complex. More than 1000 such technologies have been identified. More technologies are being added to the D&D technology inventory almost continuously as the worldwide technology search continues.

The D&D program addresses the four major EM Science and Technology (S&T) Program objectives identified in the EM Strategic Plan for Science and Technology through the following activities.

- Meet high priority needs

  – Ensure programmatic goals and strategies target end-user needs and those needs designated on the critical path to closure list.

  – Ensure full and open communication between end users, technology developers, and technology providers.

  – Nurture private sector partnerships to develop common solutions and to address common problems.

  – Provide a balanced portfolio of near- and long-term RD&D investments.

- Reduce cost of EM’s major cost centers

  – Analyze ACPtC data to identify and assess major D&D cost centers, and develop “project level roadmaps” which lead to the development of near- and long-term solutions to reduce costs.

  – Develop technologies through supporting programs

  – Demonstrate improved and innovative technologies side-by-side with baseline technologies as part of ongoing D&D activity.

  – Collect all necessary data to fully assess the cost and performance of the improved or innovative technology against the baseline.

- Reduce EM’s technological risk

- Consider risk-based criteria in the RD&D portfolio investment analysis.
- Utilize project-level roadmaps to ensure RD&D investments address critical needs and technological gaps, and reduce the cost, schedule, and technology risk associated with cleanup
- Conduct human factor evaluations to ensure worker safety and health considerations are taken into full account during development.
- Reduce risk and liability associated with first-time technology use through demonstration in a large scale D&D demonstration project.
- Take advantage of successful demonstrations/deployments by transferring technology to multiple sites for further application.

▪ Accelerate technology deployment

- Buy technologies (if available in the private sector), rather than make.
- Demonstrate technologies in ongoing D&D line projects, rather than develop.
- Conduct unbiased cost analyses and publish cost and performance reports for all demonstrated technologies.
- Develop through supporting programs (Industry/University Programs, Crosscutting Programs and EM Science Program).

Problem Area Uncertainties

EM's D&D life cycle cost estimate at $12.5 billion is a known understatement. It represents about 33% of the total estimated cost ($33B) for all DOE D&D activities. EM's D&D problems are grouped into specific site projects with each such project describing the site history, D&D problem, and current and outyear funding scenarios. Even within the complex-wide planning process now underway, these projects do not describe all of the buildings, and do not capture all of the outyear costs/mortgages for cleanup and disposition. This has created a serious funding deficiency for D&D activities within the EM technology program due primarily to uncertainties with facility end state decisions and the low outyear costs/mortgages estimates for facility D&D. As a consequence, the life-cycle cost for completing D&D will be higher than currently recognized and the full potential benefits of science and technology investment are not currently seen.

In contrast to other EM problem areas (i.e., high-level waste, mixed waste and environmental remediation), considerable D&D expertise resides in the commercial nuclear sector, both within the nuclear utilities and the commercial contractor firms which perform their D&D. The present strategy is to gradually transition the D&D investment portfolio from its current near-term emphasis on technology demonstrations and deployments to technology development aimed at solving post-2006 cleanup needs (90% of EM's D&D mortgage is post-2006). These new activities will include applied R&D through engineering of production prototypes performed within the Crosscutting Program, and will play off current basic research selected and funded within the Environmental Management Science Program. This post-2006 period is where most of the technical uncertainty exists and is, consequently, also the period when the benefits of science and technology investment are likely to be greatest.

End states for most DOE buildings have not been defined and will not be fully defined for many years. As mentioned earlier, most D&D is conducted as a non-time-critical removal action and is, therefore, often subject to schedule delays. Where defined end states exist, they range from institutional controls to assorted states of brownfields to a few greenfields. End states for most facilities are being (or will be) negotiated with State and Federal regulators and local stakeholders. Until facility end state decisions are made, uncertainties in planning and funding D&D technology projects will persist. While these uncertainties make the precise definition of future needs impossible, they increase the probability that investments in science will pay off in applications that are not now recognized.

R&D Investment Trends and Rationale

In a recent report by the DOE Chief Financial Officer, the additional D&D mortgage for DOE-Defense Programs (DP), Nuclear Energy (NE), and Energy Resources (ER) is estimated to be $20 billion, cumulatively. EM will gradually accept responsibility from DP/NE/ER for the D&D of these buildings. As mentioned previously, the estimated total D&D mortgage for DOE is at least $33 billion. This mortgage, though daunting, represents a significant opportunity for the development and widespread deployment of improved technologies to reduce the life cycle cost of facility decommissioning activities.

The current D&D R&D portfolio (Figure 9-3) has been developed to address problems identified for facilities in the EM arena. As new, potentially unique facilities are added, new problems and new science and technology needs which translate into opportunities for gainful investment may be expected to arise.

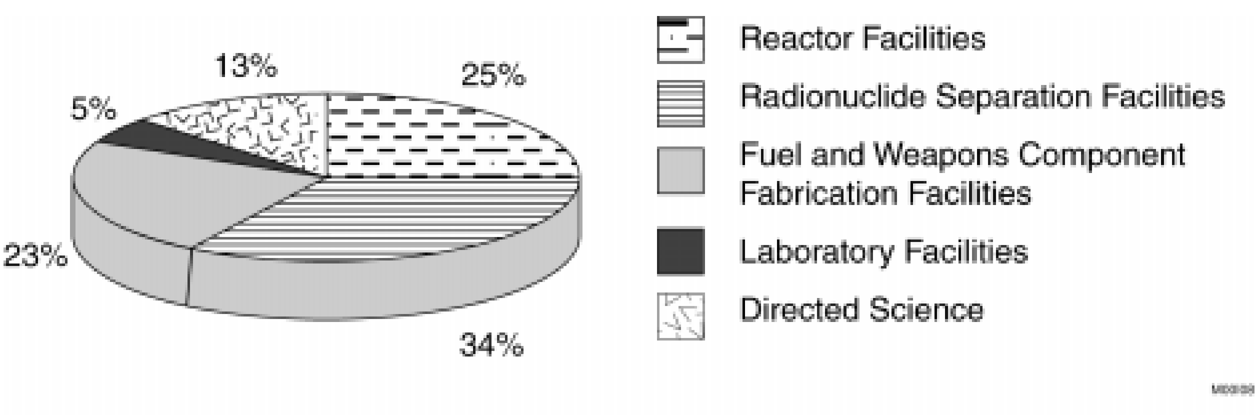


Figure 9-3. Cumulative investment in D&D areas over 3 years (FY 1999–FY 2001).

Key R&D Accomplishments

The EM D&D technology program has already achieved a number of successes, including:

- Provided technical solutions (i.e., site claimed deployment commitments and other non-claimed deployments including ASTDs) to 33 of the presently known 158 site needs with D&D technologies already demonstrated.

- Potential solutions have been identified, which if deployed may partially or completely satisfy, an additional 52 site needs with DOE-EM identified technologies.

- Demonstrated 73 improved and innovative technologies at full-scale in the first three completed and four ongoing Large-Scale Demonstration and Deployment Projects (LSDDPs).

Of the 73 demonstrated technologies, 34 have been deployed subsequent to the LSDDP. These deployments can be broken down into the following D&D operational areas: (1) Characterization, (2) Decontamination, (3) Dismantlement and Material Disposition, and (4) Worker Health and Safety.

Eight characterization technologies have been deployed a total of 39 times. Examples of deployed characterization technologies include:

- Deployment of the Surface Contamination Monitor and Survey Information Management System (SCM/SIMS) at Hanford, Rocky Flats, INEEL, Argonne, Bonus Research Reactor in Puerto Rico, and the Connecticut Yankee Nuclear Power Station. This automated surveying system records and displays real-time data for surfaces contaminated with alpha and beta/gamma radiation, and has been used to characterize over 600,000-sq. ft. of floor space at these sites. This system is appreciably faster than traditional baseline technologies for accurately surveying for both alpha and beta/gamma radiation. It helps accelerate D&D schedules.

- The GammaCam Radiation Imaging System, a 2-D gamma imaging system, has been deployed at the Chicago Pile 5 Research Reactor, Wolf Creek Nuclear Operating Corporation, Hanford’s B Plant, Peach Bottom Atomic Power Station, Limerick Generating Station, Arkansas Nuclear One Reactor, INEEL, and the USS Nimitz. This technology provides high gamma-ray energy sensitivity and remote operation capabilities, which have helped eliminate worker exposure risks and accurately maps gamma radiation sources. An upgraded 3-D GammaCam has also been demonstrated at the Hanford Canyon Disposition Initiative and subsequently deployed.

- The Laser Assisted Ranging and Data System (LARADS), a radiological mapping system, has been deployed at Hanford’s C, F, and DR Reactors, the West Valley Demonstration Project, and Hanford’s 221-1 B Plant. LARADS has been successfully used to map over 90,000-sq. ft. of floor and wall surfaces, providing a clear and concise representation of the measurement and location of contaminants that is acceptable for regulatory review and is cheaper than some of the current baseline methods.

Seven decontamination technologies have been deployed fifteen times. Highlights of deployed decontamination technologies include:

- The Centrifugal Shot Blast System, an abrasive blasting technology for concrete and coating removal, has been deployed at a NRC Plutonium/Uranium facility at the Parks Township Site and at the Fernald Site. The Centrifugal Shot Blast System has a significantly faster production rate than some of the conventional baseline methods and has been used to decontaminate 2,500 sq. ft. of floor surfaces.

- The Concrete Grinder, a handheld concrete and coating removal system, has been deployed at the Hanford C Reactor. It is faster than conventional baseline technologies and thus helps accelerate project schedules. It is also lightweight and has reduced vibration, resulting in decreased operator fatigue. It provides a smooth finish, which allows for more reliable final surveys.

Eleven dismantlement and material disposition technologies have been deployed forty times. Highlights of deployed dismantlement and material disposition technologies include:

- The Oxygasoline Torch, a cutting torch technology, has been deployed at Fernald, Oak Ridge, Pantex Plant, sites in Russia and Kazhakstan, INEEL, and Hanford. The Oxygasoline Torch cuts faster, cleaner and cheaper on thick metal and under adverse conditions (rust) in comparison to the oxyacetylene torch, as well as providing significant cost savings.

- The Soft-Side Waste Container (SSWC) was deployed throughout various facilities at INEEL. The SSWC was used to package debris such as soil, concrete, and asbestos. The SSWC packaged three times as much waste as the baseline metal and wooden crates. It was also much less expensive, providing significant cost savings.

In the worker health and safety category, eight technologies have been deployed thirty-two times. Highlights of deployed health and safety technologies include:

- The Wireless Remote Monitoring System, a personnel and area monitoring system, was deployed at Hanford’s C Reactor, Hanford’s N Basin Project, Chernobyl’s Unit 4 Shelter Project, and the Cooper Nuclear Power Station. The Wireless Remote Monitoring System provides real-time monitoring of worker dose levels, helping reduce the risk of worker exposure.

- The Personal Ice Cooling System (PICS) has been deployed at Fernald, the Nevada Test Site, Savannah River, INEEL, and Rocky Flats. PICS is a self-contained core body temperature control system that has been successfully used during high temperature D&D activities to increase worker productivity and comfort, and decrease cost compared to baseline heat stress management technology.

These 34 deployed technologies have resulted in 126 individual applications or deployments.

The above list includes several deployments in commercial plants, showing the mutual benefits of the DOE-Industry partnership in D&D technology development.

Key R&D Issues

Although DOE's investment in D&D R&D is expected to continue to return significant value in the form of technology deployments that are faster and cheaper, there are issues that will limit the long-term return. For example, the general lack of regulatory drivers for D&D action schedules reduces the urgency of technology improvements. Thus, the more innovative improvements that could have major impacts in the post-2006 period receive very low priority.

The apparent short-term advantage that accrues from having a well-established commercial sector and, therefore, a substantial reservoir of readily deployable technologies may eventually prove to have a down side by delaying investment in less developed but potentially high-impact innovations. If accelerated schedules were to be mandated for D&D, there may not be time to bring these innovations to a deployable state. Moreover, the established commercial sector has a market interest in stating that current baseline technologies are sufficient.

Considering the magnitude of the total D&D mortgage identified above ($12.5 billion for EM, $33 billion for DOE and a greater amount for the commercial utilities), the current investment in science and technology is low ($25 million in FY 2000) particularly in light of the cost savings track record to date—20-40%. Despite this outstanding return, DOE's 199-2001 investment trend is sharply downward. Unless DOE invests in D&D science and technology at a higher rate than is currently planned, potential savings of up to $1.1 billion before 2006 and $7.4 billion after 2006 in EM costs alone will not be realized. Additional costs for the DOE as a whole and for the commercial sector will be even greater.

Currently there is an effort within the Department to engage more in early stage R&D in Robotics and Intelligent Machines (RIM). It is the express objective of this initiative to develop break-through innovations in new RIM technologies to be integrated into systems of the future to significantly reduce personnel exposure, reduce secondary waste streams, and to improve productivity. In FY 1999, a critical technology roadmap was completed for RIM at the Department level. Funding for this initiative has not yet been identified.

Problem Area R&D Program

Budget: FY99-$30.9M, FY00-$32.7M, FY01-$21.9M

Program Description

The D&D R&D portfolio currently is invested in S&T resources and capabilities that range from directed research to technical assistance and which are coordinated with other EM programs to deliver integrated, technically defensible solutions for cleanup and environmental stewardship of DOE sites. EM's D&D technology program focuses on rapid deployment of improved and innovative solutions to lower cost and risk associated with D&D. EM's D&D investment in R&D supports the four major thrust areas of the EM Science and Technology program: (1) accelerate technology deployment, (2) reduce cost, (3) meet high priority needs, and (4) reduce EM's technological risk. To achieve this strategy, the D&D activities must quickly access, demonstrate, and validate the many commercially available D&D technologies available worldwide which are not currently being used within the DOE weapons complex. Over 1000 such technologies have been identified, and more are being added to the D&D technology inventory as the worldwide technology search continues.

EM manages a series of Large-Scale Demonstration and Deployment Projects (LSDDPs) designed to meet the technical needs and reduce the cost of facility D&D. In these LSDDPs, the science and technology program participates directly in site D&D projects (selected competitively) to demonstrate and validate a suite of potentially improved D&D technologies within these site projects. The first three LSDDPs, conducted in FY 1996 and FY 1997, were (1) CP-5 Research Reactor D&D at ANL-E, (2) Plant 1 Uranium Processing Facility D&D at Fernald, and (3) 105-C Production Reactor Interim Safe Storage at Hanford. These three completed LSDDPs resulted in 58 technology demonstrations, and 114 subsequent deployments of demonstrated technologies, both within DOE and the commercial nuclear utilities.

Four new LSDDPs were initiated in FY 1998. These four were: (1) TRU Waste Characterization, Decontamination, and Disposition at LANL, (2) Decontamination and Decommissioning of Fuel Storage Canals and Associated Underwater and Underground Facilities at INEEL, (3) Decontamination and Decommissioning of a Tritium Contaminated Facility at Mound, and (4) Deactivation of 321-M Fuel Fabrication Facility at Savannah River. These four new LSDDPs have so far demonstrated 20 technologies which have resulted in twelve deployments.

Additionally, DOE initiated a canyon disposition initiative at Hanford in March 1998. The remedial investigation/feasibility study (RI/FS) process utilizes the U-Plant (a chemical reprocessing canyon) and is working toward establishing an end state decision by the end of 2000. One potential option is to remove all TRU contaminants, fill the structure with waste, and entomb the canyon as a permanent disposal facility. This potential option could reduce the canyons D&D mortgage at Hanford by more than $1 billion, and is applicable to similar chemical reprocessing facilities at SRS, Oak Ridge and INEEL.

A second new DDFA program initiated in January 1999 was the Rocky Flats Initiative. This project is critical to Rocky Flats being able to develop and implement a technical baseline for closure in FY2006 by enabling simultaneous D&D of up to three of the Plutonium laboratory buildings in the FY2001-2006 period, rather than sequentially. This work is closely coordinated with two Rocky Flats Accelerated Site Technology Deployment (ASTD) projects. The first

ASTD supported rapid deployment of a commercially available characterization system, and improved cutting and size reduction tools. The second ASTD supports an interim size reduction system comprised of a remotely operated robotic arm with tooling and a Permacon enclosure.

In addition to the two Rocky Flats ASTDs, the DDFA also manages 10 other ASTD projects. The ASTD program provides incentive to the DOE sites, through cost sharing, to actually deploy improved technologies.

To effectively manage its RD&D program, four product lines were created based upon the types of facilities for which DOE is responsible: (1) reactor facilities, (2) radionuclide separations facilities, (3) fuel and weapons component fabrication facilities, and (4) laboratory facilities.

Reactor Facilities

Budget: FY99-$9.2M, FY00-$8.4M, FY01-$3.6M

Description. There are 14 surplus production reactors across the DOE weapons complex, which represent a significant portion of the long-term D&D mortgage. There are also over 100 test and research reactors throughout DOE and U.S. universities, as well as many commercial nuclear reactors that are approaching their life expectancy. Improved technologies are required that facilitate lower cost and reduced risk for D&D of these reactors. In addition to the reactor cores and central reactor facility, highly contaminated fuel pool and associated facilities requiring improved technologies for characterization, decontamination and dismantlement are also addressed.

R&D Challenges. Nuclear reactors around the world pose a multitude of challenges to D&D including auxiliary systems, piping, ventilation systems, fuel storage basins, biological shields, and reactor structure and core components. The D&D cost per commercial reactor has been estimated at $400-500 million.

R&D Activities. Improved technologies for characterization, decontamination and dismantlement that will lower overall cost to D&D these aging facilities as well as reduce risks to workers involved in D&D operations. These improved/innovative technologies will be demonstrated and deployed to help facilitate interim safe storage of DOE’s production reactors to help reduce long term surveillance and maintenance costs. Improved technologies in the areas of debris/sludge removal from fuel storage pools, fuel storage pool water treatment, and decontamination of the storage pool surface will also be demonstrated.

Planned Accomplishments:

- Review EMSP grants for potential transfer to applied R&D within this product line, and assess new science needs for EMSP basic science solicitation.
- Initiate integration of characterization sensors for high-rad difficult to access areas.
- Demonstrate Integrated Vertical & Overhead Decontamination System.
- Demonstrate and deploy (non-DOE) Ex Situ Large Bore Pipe Decon & Characterization System.

- Develop and deploy a low-cost D&D system based on commercially available Brokk system and the compact remote operator console developed by ORNL.
- Complete deployment of innovative characterization technologies (i.e., ISOCS) as part of the MARSSIM implementation at BNL.
- Deploy two technologies (3-M Empore and Selion Graver Nuclide Removal System) for cleanup of Savannah River basin liquids.
- Complete Fuel Storage Pools & Associated Structures LSDDP with demonstration of four to six new and innovative D&D technologies.
- Demonstrate Remote Surveillance of Facilities Awaiting D&D.

Radionuclide Separation Facilities

Budget: FY99-$9.3M, FY00-$10.2M, FY01-$9.5M

Description. Improved technologies are required to deactivate and decommission radionuclide separation facilities, including gaseous diffusion plants, fuel reprocessing canyons, chemical separation facilities, uranium recycling facilities, lithium enrichment facilities, and heavy water production facilities. D&D activities also lead to potential valuable resources, such as scrap metal and concrete. At present, most of these materials are disposed of as waste because of cheap burial costs. Decontamination of concrete and metals for recycle or free release may result in many project life cycle cost savings.

R&D Challenge. Radionuclide Separation Facilities are typically massive in size, are aging structures, and have high levels of contamination. These facilities have been used to process plutonium, uranium and various hazardous materials. Removal and disposition of radioactive and hazardous materials and equipment, deactivation of nonessential systems and utilities, and reconfiguration of systems to facilitate long-term surveillance and maintenance within these facilities with baseline technologies is very costly and poses high safety and health risks. Material generated during D&D activities is currently disposed of as low-level waste at typically high-life cycle costs. The ability to characterize and segregate contaminated and non-contaminated material will result in substantial life cycle cost savings.

R&D Activity. Technologies will be demonstrated and deployed which address characterization of specific contaminants, large-scale decontamination and dismantlement, waste disposition, worker health and safety, and remote operations. Technologies will also be demonstrated and deployed to accurately characterize and determine the type, quantity, and location of contamination to support development of a Record of Decision (ROD) to determine the final end-state of the U-Plant facility at Richland. Finally, improved technologies for rapid radioactive analysis and separation into contaminated and non-contaminated scrap material will be demonstrated and deployed for substantial life cycle cost savings.

Planned Accomplishments:

- Review completed EMSP grants for potential transfer to applied R&D within this product line, and assess new science needs for EMSP basic science solicitation.
- Evaluate, integrate, and demonstrate multiple sensors for material characterization and segregation.
- Develop, demonstrate, and deploy a high productivity vacuum blasting system.
- Evaluate, integrate, and demonstrate detection instruments for real-time volumetric radioassay of lead forms.
- Assemble and integrate compact remote operator console with the equipment pit D&D system.
- Demonstrate Online Measurement of the Progress of Decontamination.
- Complete Life-Cycle Costs Analysis of Radioactive Scrap Metal Disposition.
- Develop and integrate computer control architecture required to support enhanced telerobotic control compatible with the compact remote operator console for equipment pit D&D, including integration of the Robotic Task Space Analyzer.
- Initiate demonstration of AEA technology to decontaminate contaminated equipment, including possibly canisters and other waste processing equipment associated with the SRS and WV waste vitrification.
- Complete Dual Point Impedance Control system development for enhanced telerobotic operations.
- Complete Canyon Disposition Initiative with the demonstration/deployment of two to four new and innovative characterization technologies.
- Deploy Position Sensitive Radiation Monitor (Surface Contamination Monitor) at NTS.
- Complete fabrication and deployment of Laser Cutting System at NTS TRU waste size reduction.
- Conduct and complete INEEL implementation of innovative processes for Recycle and Release of Concrete from D&D projects.
- Deploy Personnel Ice Cooling System throughout DOE sites.
- Deploy Mobile Work Platform for D&D operations at Fernald.

- Assess unmet needs associated with Radionuclide Separation Processing Facilities to determine R&D path forward beginning in FY2001.

- Initiate and complete one (maybe two) LSDDPs (e.g., Scrap Metal Recycle & Release or Processing Facility D&D).

Fuel and Weapons Component Fabrication Facilities

Budget: FY99-$5.7M, FY00-$8.6M, FY01-$5.3M

Description. Improved technologies are required to deactivate and decommission fuel and weapons component fabrication facilities including uranium milling and refining facilities, fuel and target fabrication facilities, weapons component fabrication facilities and weapons disassembly, dismantlement, modification and maintenance facilities.

R&D Challenges. Problems that will need to be addressed include: decontamination /dismantlement and metal/concrete waste disposal/recycling; characterization and removal of highly enriched uranium at fuel fabrication facilities; and characterization, decontamination and dismantlement of weapons component fabrication facilities that contain highly fissile materials, and numerous radioactive species, organics, and high explosive materials.

R&D Activities. Technology emphasis will be on real-time characterization, removal of tritium and highly enriched uranium from inaccessible areas, decontamination and remote dismantlement technologies that will significantly reduce the risk to workers, the public, and the environment.

Planned Accomplishments:

- Review completed EMSP grants for potential transfer to applied R&D within this product line, and assess new science needs for EMSP basic science solicitation.

- Complete development of the Alpha Continuous Emission Monitor

- Complete development of the Modular Manipulator for robotic applications in glove boxes.

- Demonstrate In Situ Pipe Decontamination System

- Initiate development of a real-time surface characterization system for beryllium for application at Rocky Flats.

- Initiate development of a beryllium air monitoring system for application at Rocky Flats.

- Deploy Remote/Robotic Size Reduction System for RFETS Building 776.

- Deploy Decontamination and Volume Reduction System at LANL

- Procure and fabricate Central Size Reduction Facility at Rocky Flats
- Complete Mound LSDDP for D&D of Tritium Facilities demonstrating four to six technologies.
- Close out LSDDP for Deactivation of Savannah River's 321-M HEU Facility.
- Complete LANL LSDDP with demonstration of four to six technologies.
- Initiate and complete possible LSDDP (e.g., High Explosives Facility).
- Demonstrate/deploy technologies developed through IP/UP to address high-priority needs based on assessment of unmet needs associated with Fuel and Weapon Components Fabrication Facilities.

Laboratory Facilities

Budget: FY99-$4.6M, FY00-$0.0M, FY01-$0.0M

Description. Innovative and improved technologies are required to deactivate and decommission laboratory facilities including research, development and testing facilities, hot cells and gloveboxes.

R&D Challenges. Across the DOE weapons complex, there is a large number of surplus plutonium contaminated processing equipment including piping, ducts, tanks and gloveboxes characterized as TRU waste. To limit the amount classified as TRU, an improved waste management process that will characterize, sort, and segregate TRU and LLW is needed. Laboratory facilities including hot cells and gloveboxes are typically contaminated with high levels of radioactivity and often require remote/robotic applications to reduce worker exposure risk. Working space is often confined, which results in increased worker risks. Laboratory facilities are generally large structures with complex equipment and piping systems requiring repetitive robotic dismantlement and size/volume reduction techniques. These facilities usually have large areas of contamination on concrete and metal surfaces requiring characterization, decontamination and disposition of radioactive lead shielding, dust and debris removal, and remote cutting. Without this effort, baseline D&D approaches will be followed at most all DOE sites at typically very high costs.

R&D Activities. Laboratory facilities will address basic research, applied research, demonstrations and deployments of technologies and techniques for the D&D of laboratory facilities including hot cells and gloveboxes. D&D of these facilities, typically contaminated with high-levels of radioactivity, will require remote/robotic applications to reduce worker exposure risk. The R&D is to develop remote/robotic systems that can operate in the confined working space often found in these facilities.

Planned Accomplishments:

- Review completed grants for potential transfer to applied R&D within this product line and assess new science needs for basic science solicitation.

- Assess unmet technical needs associated with Laboratory Facilities to determine R&D path forward beginning in FY2002.
- Deploy Remote Work Platform for Size Reduction of B Cell at Hanford
- Possible initiation and completion of LSDDP (e.g., Hot Cell and Associated Laboratory Equipment D&D or Storage and Treatment Facility D&D).
- Complete applied and advanced/engineering development through IP/UP to address high-priority needs based on assessment of unmet technical needs associated with Laboratory Facilities.

Directed Science

Budget: FY99-$2.1M, FY00-$5.5M, FY01-$3.5M

Within the D&D investment portfolio, DOE funds research to advance science to solve environmental problems associated with placing equipment and structures in a desired end state. Desired end states include complete removal and remediation of the facility, release of the facility for unrestricted use, or release of the facility for restricted use. Nine subcategories of science needs have been identified in the area of deactivation and decommissioning:

- Reduction of wastes produced by remediation and decontamination.
- Characterization, monitoring, and certification of contaminated equipment facilities.
- Control of radioactive emissions, especially from waste processing activities.
- Improved methods for removing surface contamination, including metals, concrete, and non-porous surfaces.
- Containment technologies/techniques to prevent spread of contamination.
- Methods for size reduction in equipment.
- Technologies for removal of hazardous materials, including asbestos and lead.
- Remote handling and operations, including demolition.
- Decontamination techniques for process equipment and facilities.

Between 1998 and 2000, 22 directed research projects were being funded for a total amount of $13.5 million. Four were completed in FY99. A new solicitation will go out in FY2000. The D&D basic research portfolio is concentrated in the scientific areas of analytical chemistry and instrumentation, biogeochemistry, engineering science, inorganic chemistry, materials science and separations chemistry.

Analytical Chemistry and Instrumentation: Focus is on waste characterization equipment and techniques. The objectives of this basic research project are to develop nondestructive methods for identifying the hazardous asbestos in real-time in the field using gamma spectroscopy. Another project aims to develop simple, inexpensive new chemical sensing materials which can be used as visual color test strips to sensitively and selectively report on the concentration and identity of environmental pollutants such as cations of lead, uranium, plutonium, strontium, cesium, and cobalt, as well as other species.

Biogeochemistry: Focus is on improved methods for removing surface contamination. Projects include biological and physical chemical parameters for effective decontamination of metal surfaces using environmentally benign aqueous-based biopolymer solutions, and microbial processes with potential for decontaminating corroding metal surfaces.

Engineering Science: Focus is on robotics development and monitoring devices. Projects include work leading to a prototype dual-manipulator mobile work cell, which is supported and enhanced by computer vision, artificial intelligence, and virtual reality technology; avoiding the dangers associated with in-operation failure of robots to help DOE personnel reduce the risk of catastrophic in-site robot failures and thereby decrease the risk of damaging the containment facilities, loss of robot, and mission failures; and developing three-dimensional position-sensitive germanium detectors with the ultimate goal of improving image resolution without sacrificing spectroscopic resolution in gamma-ray imaging cameras.

Inorganic Chemistry: R&D in this area centers on solid/solution chemistry. Investments are being made for a robust process, Polymer Filtration®, which can address the various conditions that dilute waste streams present. Polymer Filtration® combines specially prepared water-soluble metal-binding polymers with commercially available ultrafiltration membranes to effect a selective separation of metal ions. It is anticipated that new materials such as this one will be able to address many DOE metal removal/recovery needs.

Materials Science: Focus is on surface chemistry and waste materials. Projects include a collaborative research program to characterize the novel chemistry and physics of the atmospheric-pressure plasma jet; study of the structure, composition, and mechanism of formation of radionuclide-containing surface films on metals relevant to the problem of decontaminating piping systems and waste storage tanks at DOE nuclear facilities; thermal effects between 100 and 1400 degrees on concrete engineering properties, chemical properties, and contamination behavior as a function of final temperature, heating rate and aggregate type; and optimizing a melt decontamination process through a basic understanding of the factors that govern partitioning of various radionuclides between metal, slag, and gas phases to (a) determine the nature of the association of radionuclides uranium, plutonium, cobalt, and strontium with stainless steel, plain carbon steel and copper surfaces commonly found at sites targeted for decommissioning, and (b) selectively remove the radionuclides using hydroxycarboxylic acids (citric acid and its analogs).

Separations Chemistry: Focus is on ligand design and ion exchange. Projects include use of innovative separation techniques for highly toxic radioisotopes such as plutonium and the experimental capability to handle these materials; use of colloid-enhanced ultrafiltration processes to remove and recover important radionuclide ions and associated contaminants from aqueous streams; and application of unique quantitative surface analytical capabilities to measure the depth-dependent radionuclide concentrations of test surfaces that represent the full range of materials and exposures found in nuclear facilities.

Robotics and Intelligent Machines (RIM): The term “robotics and intelligent machines” refers to systems composed of machines, sensors, computers and software that provide DOE with a wide range of capabilities to accelerate the rate, ability, and cost-effectiveness with which DOE can fulfill its missions. RIM is new Department-level initiative to conduct early stage, long-term R&D in the RIM Science and Technology bases: Action, Perception, Reasoning, and Novel Interfaces and Integration Systems (i.e. Human-Machine Interface). RIM technologies could help the Department meet a number of overarching long-term challenges which are typical of those faced by D&D. It must:

- Remove its workers from almost all hazardous environments as a result of rising safety awareness and the availability of enabling technologies;
- Lower the cost of its operations, including cleanup, in the face of inflationary and other pressures on its budget;
- Reduce the environmental impact of its operations; and
- Find the means to perform operations that are necessary, but impossible for humans to perform, and for which no alternatives currently are available.

The RIM initiative is applicable to several waste and material types, including problem areas discussed in other chapters. It is described here due to its high degree of applicability to D&D. It is currently envisioned that RIM R&D in the following target areas will specifically facilitate D&D operations to meet the challenges above:

- Advanced Remote Handling
- Advanced Waste and Task Environment Characterization
- Remote Work System Mobility
- Task-Driven Computer-Aided Engineering
- Remote Operator-Machine Interface/Cooperation
- Remote Operations Simulation and Training

Budget Summary Table

(Dollars in thousands)

Program Activity	FY 1999 Appropriation	FY 2000 Appropriation	FY 2001 Request
Reactor Facilities	9,157	8,419	3,645
Radionuclide Separation Facilities	9,322	10,189	9,462
Fuel and Weapons Component Fabrication Facilities	5,742	8,627	5,265
Laboratory Facilities	4,574	0	0
Directed Science	2,128	5,451	3,502
Total	**30,923**	**32,686**	**21,874**

Chapter 10
Basic Science

Chapter 10
Basic Science

Table of Contents

Overview

The Department of Energy has the responsibility for the cleanup of the nuclear weapons complex, the nation's largest environmental program. The cleanup program "faces many problems that will require new knowledge and fundamental understanding of basic chemical, physical, geological, and biological processes and their relationship to risk" as stated by a committee of the National Research Council [*Building an Effective Environmental Management Science Program*, National Academy Press, 1997, page vii].

In addition, energy and the environment pose major scientific and technological challenges for the 21st century. New technologies for increasing the efficiency of harvesting and utilizing energy resources are essential to the nation's economic competitiveness. At the same time, the quality of life in the United States depends inherently on the environmental impact of energy production and utilization. This *interdependence* of energy use and environmental consequences makes it imperative to develop a better basic scientific understanding of the environment in support of new strategies for minimizing the impact of energy-related activities.

The two major Offices within the Office of Science (SC) that have Environmental Quality R&D responsibilities are the Office of Basic Energy Sciences (BES) and the Office of Biological and Environmental Research (BER). Both of these offices have basic science programs that have been addressing environmental quality issues, in some cases since the beginning of the Atomic Energy Commission. The BER Program mission is to advance environmental and biomedical knowledge connected to energy. Through its support of peer-reviewed research at the national laboratories, universities, and private institutions, the program develops the knowledge needed to identify, understand, and anticipate the long-term health and environmental consequences of energy production, development, and use. The mission of BES is to foster and support fundamental research in the natural sciences and engineering to provide a basis for new and improved energy technologies and for understanding and mitigating the environmental impacts of energy use. As part of its mission, BES plans, constructs, and operates major scientific user facilities to serve researchers at universities, national laboratories, and industrial laboratories. In addition, SC's Office of Advanced Scientific Computing Research (ASCR) supports fundamental research in advanced computing research—applied mathematics, computer science, and networking—and operates supercomputer, networking, and related facilities to enable the analysis, modeling, simulation, and prediction of complex phenomena important to the Department of Energy, including its portfolio of environmental science research.

This chapter describes the basic research related to environmental quality that is supported by each of these offices. The chapter is organized by scientific discipline, starting with Biology, Plant Sciences and Bioremediation, and continuing through Chemistry, Computational Science, Engineering, Geosciences, and Global Change (including the multi-disciplinary Climate Change Technology Initiative) to Materials Science. A final section covers major scientific user facilities.

Another important science research program that is directed to environmental cleanup and waste issues for the Department's operations is the Environmental Management Science Program (EMSP). Elements of the EMSP are discussed in other chapters of this report where there are potential applications of the basic research this program supports. Chapter 10 discusses the fundamental basic science questions addressed by this research and the basic knowledge that is sought through such investigations.

Biology, Plant Sciences and Bioremediation

The biological sciences are coming to the forefront in the Department's environmental research portfolio, thanks to recent fundamental advances in this area, such as the dramatic progress in the genome program, and to a realization that many of DOE's environmental problems cannot be addressed without incorporating the best current research in biology. For example, DOE is supporting fundamental studies to determine the place of microbial bioremediation for dealing with contamination underground that is inaccessible to conventional methods of treatment or that would be too expensive to manage using nonbiological treatment techniques. Likewise, phytoremediation (the use of plants to treat or sequester contaminants) is a very promising technique for dealing with contaminants since plants develop extensive networks of roots in the ground (as much as millions of miles of roots under one acre) that can remediate large underground volumes without constructing an extensive infrastructure as is needed for conventional treatments.

Natural and Accelerated Bioremediation Research

The mission of the Natural and Accelerated Bioremediation Research (NABIR) Program is to provide the scientific understanding needed to make use of natural processes and to develop methods to accelerate these processes for the bioremediation of contaminated subsurface sediments and groundwater at DOE facilities. The program focuses on in situ bioremediation of heavy metals and radionuclides. Scientific understanding will be gained from fundamental laboratory and field research on biotransformation processes, community dynamics and microbial ecology, biomolecular science and engineering, biogeochemical dynamics, and innovative methods for accelerating and assessing *in situ* biogeochemical processes. Field research centers and the supporting infrastructure will facilitate long-term, interdisciplinary research. Computational models will be developed as integrating tools; also they will provide methods for predicting and improving the effectiveness of bioremediation. Additionally, societal implications will be studied to contribute to the appropriate use of bioremediation technologies in safe manner.

The NABIR program provides a framework of basic research in each of seven key areas needed to extend the applicability of bioremediation to many of the environmental problems found at DOE facilities: (1) Biotransformation, (2) Community Dynamics and Microbial Ecology, (3) Biomolecular Sciences and Engineering, (4) Biogeochemical Dynamics, (5) Assessment, (6) Bacterial Transport, and (7) System Engineering, Integration, Prediction and Optimization.

Microbial Genome Program

The Microbial Genome Program focuses on: (1) Genomic sequencing. Microbes are selected for sequencing based on their relevance for energy production, the global cycle, and bioremediation; (2) Microbial diversity. Information is needed on the diversity of microbial species from environments of potential importance to DOE missions, e.g., environments contaminated by high concentrations of toxic metals, and/or radionuclides, likely to contain microbes with metabolic or biochemical properties of potential utility for DOE's missions in waste remediation and clean up, cellulose degradation and energy production; (3) Leveraged sequencing. Strategies are needed that use a previously determined microbial genomic sequence to rapidly, accurately, and cost effectively determine the entire genomic sequence of a related species; (4) Development of improved tools for annotation and analysis of microbial genomic sequence data. This is a critical and fascinating part of the Microbial Genome Project since more than half of the genes identified in newly sequenced microbes are unrelated any genes that have previously been discovered. These new genes represent exciting opportunities for future basic research and potential sources of biological resources to be mined for future use.

Energy Biosciences Program

The Energy Biosciences Program supports mechanistic research on fundamental biological processes related to capture, transformation, storage and utilization of energy. The research focuses on plants and nonmedical microorganisms to form a broad scientific foundation for support of Department of Energy s goals and objectives in energy production, environmental management, and energy conservation. Basic research on plants includes photosynthetic mechanisms and bioenergetics in algae, higher plants, and photosynthetic bacteria; control mechanisms that regulate plant growth and development; fundamental aspects of gene structure, function, and expression; plant cell wall structure, function and synthesis; and mechanisms of transport across membranes. Research supported in these areas seeks to define and understand the biological mechanisms that effectively transduce light energy into chemical energy, to identify the biochemical pathways and genetic regulatory mechanisms that can lead the efficient biosynthesis of potential fuels and petroleum-replacing compounds, and to elucidate the capacity of plants to remediate contaminated environments by transporting and detoxifying toxic substances. The research focus in the microbiological sciences includes the degradation of biopolymers such as lignin and cellulose, anaerobic fermentations, genetic regulation of microbial growth and development, thermophily, e.g., bacterial growth under high temperature, and other phenomena with the potential to impact biological energy production, conversion and conservation. Organisms and processes that offer unique possibilities for research at the interface of biology and the physical, earth and engineering sciences are also studied.

Bioremediation and Phytoremediation

Bioremediation and phytoremediation are a significant focus of basic science funded by the EMSP. The projects in this area can be classified into the following subdisciplines: biodegradation and biotransformation, microbial genetics, microbial transport, plant genetics, plant membrane transport, plant metabolism, biogeochemistry, and bioengineering. In this program element scientists are, for example, studying the genetics and structural biology underlying the mechanisms by which certain plants take up heavy metals, radionuclides and chlorinated hydrocarbons from contaminated soil and groundwater systems. An early success in this area is the discovery of means to design plants genetically to convert the extremely toxic methylmercury compounds into less hazardous forms. Several projects are studying bacteria that can live in extreme environments such as high radiation fields or high temperatures in order to understand how microorganisms might be used to transform contaminants into less toxic forms. An additional group of projects in the biological sciences is focused on basic understanding of health effects of chemical contaminants and radiation.

Chemistry

Chemistry, with its focus on the molecular level, plays a central role in addressing the needs for fundamental understanding and technology development in both the energy and environmental fields. Understanding environmental processes and consequences requires studying natural systems, rather than focussing exclusively on laboratory models. Natural systems and their complexity pose an enormous, perhaps the ultimate, challenge to chemists, and will provide them with varied and exciting new problems for years to come. In addition, the complexity of the underlying systems and processes often requires multi-disciplinary programs that bridge the interfaces between chemistry and other disciplines. Several major program elements in the chemical sciences support environmental quality R & D. The disciplinary areas within each component are connected to and address the basic research needs of the Department's principal environmental mission goals and objectives.

Heavy Element Chemistry

Developing the fundamental understanding of the underlying chemistry of the actinide elements and separations is important for implementing effective technologies related to pollution prevention, environmental remediation and waste management. The heavy element chemistry program focuses on advancing the knowledge base of the chemical and physical properties of the actinide elements, principally the transuranium elements. A variety of scientific investigations are being pursued within the program, including basic chemical research in near-neutral aqueous solutions, chemistry of aqueous complexing agents, preparative methods for metals and compounds, organometallic chemistry, the chemistry of excited spectroscopic states, thermochemical studies, and characterization in the solid state. The program provides the principal source of new knowledge related to fundamental chemistry of actinide elements with importance to the Department's stewardship responsibilities of these materials, because of their importance to nuclear technology, to the remediation of former weapons production sites, and to applied chemistry efforts in environmental management.

Separations and Analysis

This activity supports basic research to develop better analytical methods for a wide variety of applications in energy processes and environmental sciences, and to improve our understanding of methods for separating mixtures of gases, liquids, solids, and their component molecules, metal cations and anions. Chemical and physical principles that can lead to entirely new methods of analysis are investigated. The research addresses the fundamental molecular level questions underlying separations processes. The program covers a broad spectrum of separations concepts, including membrane processes, extraction under both standard and supercritical conditions, adsorption, chromatography, photo-dissociation, and complexation. The analysis activity supports research on phenomena basic to analytical methods with the goal of improving the sensitivity, reliability, and/or productivity of analytical determinations. Research in this program also encompasses methods for describing turbulent combustion and predicting thermophysical properties of multicomponent systems, where significant energy savings are possible. The science has wide applicability and strong links to the separations and analysis efforts in environmental management.

Catalysis and Chemical Transformations

This program focuses on research related to heterogeneous and homogeneous catalytic systems and to new catalysts for the production of fuels and chemicals, better analytical methods in a wide variety of applications in energy processes and environmental sciences, and new or existing concepts of energy production and storage. Research encompasses chemical aspects of catalysis, both heterogeneous and homogeneous; the chemistry of fossil resources; the conversion of biomass and related cellulosic wastes; and the chemistry of precursors to advanced materials. Creating new, less-energy-demanding routes for the production of basic chemical feedstocks and value-added products is important to energy efficiency. General research that underpins a fundamental understanding of chemical reactivity is also vital, and this, in turn, enables the production of more efficient combustion systems with reduced emissions of pollutants. Understanding of molecular level processes at surfaces, interfaces, and in bulk media are also important to environmental management issues related to pollutant transport and containment.

Photochemistry and Radiation Research

Employing radiation chemistry in environmental remediation requires a basic understanding of radiation chemical processes in complex environmental systems. Fundamental knowledge of how radiolytic reactions occur in heterogeneous systems, including an understanding of how the radiation source, intensity and energy effect reaction rates, mechanisms and product distributions, is required. There is a need to understand the basic mechanisms of advanced oxidation processes, establishing mechanisms of free radical reaction pathways important to remediation, the study of supercritical solvent effects in free radical reactions, and related theoretical and modeling efforts. The program also seeks knowledge of solar photoconversion processes resulting in new, improved systems and production methods. Fundamental concepts of light-induced charge separation at the molecular level are developed for application to photodriven endothermic reactions for the conversion of light energy to chemical energy altering chemical reaction pathways so that high volume industrial intermediates and specialty chemicals can be produced by less polluting processes.

Chemical Physics Research

This program investigates, at the molecular level, chemical reactions in the gas phase, at surfaces, and at interfaces and the relationship between molecular scale phenomena and bulk phenomena. Research activities involve closely-coupled experimental and theoretical efforts. Experimental projects include studies of molecular dynamics, chemical kinetics, spectroscopy, clusters, and surface science. The surface science and clusters research is aimed at providing predictive capability for surface mediated catalysis through provision of explanatory theories relating surface structure to surface mediated chemistry. One of the goals of the chemical physics program is to provide data and techniques for producing or predicting the values of chemical reaction rates to be included in combustion models for predicting the efficiency and emission characteristics of combustion devices and for optimization and control of combustion devices.

Measurement Science

This program supports fundamental research in analytical chemistry with the goal of developing new technologies for improved sensitivity, selectivity, and spatial and temporal resolution of chemical measurements. The Program has provided the basis for major new concepts for instrumentation for environmental characterization (for example, the first demonstration of detection of single atoms, a fundamental advance that led to technology for tracing isotopes in natural and contaminated environments). The program objectives include instrumentation for characterizing environmental chemical composition using spectroscopic techniques, sensors for miniaturized, automated remote monitoring of contaminated environments and technologies for determining the composition of hazardous and radioactive stored wastes.

Chemical Sciences

The chemical sciences are the discipline into which nearly half of the projects funded in the EMSP can be classified. The analytical chemistry and instrumentation component, for example, supports research into laser ablation techniques for characterizing high level wastes and solid waste forms, mass spectrometric research for characterizing hazardous wastes, research into sensors for remote measurement and monitoring of diverse species such as heavy metals, chromium, gamma-ray emitting radioisotopes, and organic contaminants. Actinide chemistry places emphasis on studying the properties of plutonium, americium, curium and the other heavy elements both in high level tank wastes and in subsurface environments. The inorganic and surface chemistry projects include fundamental studies of the chemistry of technetium, a synthetic element found in high concentration in fission products, as well as the study of catalysis of chemical reactions that could determine the long-term behavior of tank wastes or could be used to treat contaminated soils. Separations chemistry also is a major element of the EMSP with several areas of emphasis including design of new chemicals for complexing heavy metals and research into inorganic ion-exchanging materials that could be used to isolate selected contaminants.

Computational Science

In computational science, ASCR supports advanced computing research—applied mathematics, high performance computing, and networking—and operates supercomputer and associated facilities that are available to researchers 24 hours a day, 365 days a year. The combination of support for fundamental research, computational and networking tools development, and high-performance computing facilities provides scientists with the capabilities to analyze, model, simulate, and—most importantly—predict complex phenomena of importance to the Department of Energy. This capability underpins much of the computational research in support of DOE's environmental missions.

Specific examples of the complex problems relevant to environmental research which are the current focus of computational research in DOE are: climate modeling, including the effects of greenhouse gases on global climate change; the subsurface transport of pollutants; the rational design of new materials to produce, for example, new alloys, superconductors, polymers, and catalysts; theoretical studies of the chemistry of actinides; and the dynamics of multiphase viscous fluids such as oil drilling muds and waste sludges.

Engineering Sciences

In Engineering Research, the goals are to extend the body of knowledge underlying current engineering practice to create new options for improving energy efficiency and to broaden the technical and conceptual knowledge base for solving the engineering problems of energy technologies. The Engineering Research program supports work in three technical areas: (1) mechanical systems including fluid mechanics, heat transfer, and solid mechanics; (2) systems sciences including process control, instrumentation, and intelligent machines and systems; and (3) engineering analysis including nonlinear dynamics, data bases for thermophysical properties, models of combustion processes for engineering applications and foundation of bioprocessing of fuels, and energy related waste and materials. Engineering science in the EMSP includes the study of bubble mechanics and sonification processes for remediation of contamination, robotics and control systems, and on-line diagnostics for waste stream characterization.

Geosciences

In the Department's Geosciences Research program, the goal is fundamental knowledge of the processes that transport, concentrate, emplace, and modify the energy and mineral resources and the byproducts of energy production. The research supports existing energy technologies and strengthens the foundation for the development of future energy technologies. Ultimately, the research impacts control of industrial processes to improve efficiency and reduce pollution, to increase energy supplies, and to lower cost and increase the effectiveness of environmental remediation of polluted sites. The Geosciences Research activity supports basic research in geophysics and geochemistry to improve the level of understanding necessary for advances in and choices among current and emerging energy and environmental technologies. Geochemical research focuses on fundamental understanding of mineral-fluid interactions to provide a better foundation for oil, gas, and geothermal resource recovery and control of contaminants in groundwater flow; new fundamental thermodynamic and physical property information on rocks, minerals, and geologic fluids for resource recovery and contaminant assessment and monitoring; and extending the applicability of isotopic tracer methods for evaluation of natural and human-perturbed processes in the geologic environment. This information, in concert with other geosciences research, is providing the basis for efforts leading to quantitative predictive capabilities for processes that take place in the Earth's crust.

The EMSP has a major commitment to basic research in the geosciences. This emphasis, present since the start in 1996, has increased in 1999 with the heightened concern with the problems in the subsurface and vadose zone at the Hanford Site. Nearly two-thirds of the projects funded as a result of the subsurface/vadose zone solicitation are in the geosciences. The geochemistry element includes studies of solid/solution geochemistry, colloidal chemistry and transport (a critical concern for example in modeling the potential subsurface transport of plutonium is understanding the extent to which colloidal particles could transport this otherwise generally rather insoluble element), and sorption/desorption geochemistry. The latter area supports research into the factors that influence mobility of contaminants as they interact with the particle surfaces of the subsurface environment. There is a wide range of minerals that need to be studied to allow understanding of the potential mobility of contaminants at DOE cleanup sites and modeling of the transport of these contaminants under various conditions. The research includes studies of clay minerals, quartz, silica, and other naturally-occurring species, as well as materials that are components of tank sludges. The geophysics element supports a range of basic research into techniques for imaging in three dimensions contaminated subsurface environments and underground storage tanks. Among the techniques being studied are high frequency electromagnetic impedence measurement, seismic surface wave tomography and dielectric and nuclear magnetic resonance studies of pore-scale distribution of contaminants. The potential of ground penetrating radar for imaging moisture in the vadose zone is being investigated in this program element. The hydrogeology element has placed an especial emphasis on fundamental properties of dense nonaqueous phase liquids (DNAPLs) in groundwater and unsaturated subsurface environments. The relationship between underground fluid flow and contaminant transport is being investigated both through experimental studies and in research into modeling of these phenomena.

Global Change

The Global Change activities include the process research and modeling efforts needed to (1) improve understanding of factors affecting the Earth's radiant-energy balance; (2) predict accurately any global and regional climate change induced by increasing atmospheric concentrations of greenhouse gases; (3) quantify sources and sinks of energy-related greenhouse gases, especially carbon dioxide; and (4) improve the scientific basis for assessing the potential consequences of climatic changes, including the potential ecological, social, and economic implications of human-induced climatic changes caused by increases in greenhouse gases in the atmosphere and the benefits and costs of alternative response options.

Research is focused on understanding the basic chemical, physical, and biological processes of the Earth's atmosphere, land, and oceans and how these processes may be affected by energy production and use, primarily the emission of carbon dioxide from fossil fuel combustion. A major part of the research is designed to provide the data that will enable an objective assessment of the potential for, and consequences of, global warming. The program is comprehensive with an emphasis on the radiation balance from the surface of the Earth to the top of the atmosphere including the role of clouds and on enhancing the quantitative models necessary to predict possible climate change at the global and regional levels. The Environmental Processes subprogram is DOE’s contribution to the U.S. Global Change Research Program that was codified by Congress in the Global Change Research Act of 1990.

Atmospheric Radiation Measurement Program (ARM)

ARM is a key component of the Department’s research strategy to address global climate change. The Program is a direct continuation of DOE's decade-long effort to improve General Circulation Models (GCM) and to provide reliable simulations of regional and long-term climate change in response to increasing greenhouse gases. The ARM Program is a highly focused observational and analytical research effort that collects data for comparison with and improvement of GCMs. ARM operates Cloud and Radiation Testbed facilities in three climatically different locations: the U.S. Southern Great Plains, the tropical western Pacific Ocean, and the North Slope of Alaska. Data are readily available to the researchers in near-real-time. Research objectives are to describe quantitatively the radiation balance from the surface to the top of the atmosphere, to determine the atmospheric characteristics responsible for this balance, to improve the parameterization of the formation and evolution of clouds in climate models, and to operate an experimental testbed for testing process models used in GCMs and for providing satellite ground-truth measurements.

Climate Change Prediction Program

The DOE Climate Change Prediction Program is the next phase in the evolution of DOE’s long-standing climate modeling and simulation research agenda. The program is focused on developing climate simulation and prediction models that stay at the leading edge of scientific knowledge and computational technology, testing their performance and applying them to the problem of long-term climate prediction. A unique feature of the program is the establishment of a distributed modeling center involving DOE National Laboratories, the National Center for Atmospheric Research and the nonFederal research community. The program will develop models based on more definitive theoretical foundations and improved computational methods that will run efficiently on future generations of high-performance scientific supercomputers. The intent is to increase dramatically both the accuracy and throughput of computer model-based predictions of the future climate system response to the increased atmospheric concentrations of greenhouse gases.

Climate Change Technology Initiative

The CCTI basic science element focuses on the fundamental science that will enable mitigation of climate change while maintaining a robust National economy.

Eighty-five percent of our Nation's energy results from the burning of fossil fuels, a process that adds carbon to the atmosphere, principally in the form of carbon dioxide. Because of the potential environmental impacts of increases in global atmospheric carbon dioxide, carbon management is an international concern and is a focus of the Climate Change Technology Initiative, a comprehensive research and development program. The Office of Science is well positioned to make significant contributions to this problem, by building on its core programs with novel approaches to make carbon management practical and efficient. Science core programs include research on both carbon and noncarbon energy sources and on both carbon sequestration and carbon recycling. These activities can serve as the basis for new carbon management science that will lead to the technologies of the future. The theme of efficiency in energy production and use will span the entire range of research activities. Research on carbon energy sources, and their impacts, is a focal point of interagency activity through the U.S. Global Change Research Program (USGCRP). Research on noncarbon energy sources is also a focal point of intra-agency activities and is led by the DOE Office of Energy Efficiency and Renewable Energy. The DOE Office of Science, through activities in both the Basic Energy Sciences (BES) program and the Biological and Environmental Research (BER) program, supports research that underpins both efforts.

Additional science efforts will also have a major effect on a range of scientific disciplines by advancing the state of knowledge and by training students in areas of research that are important to carbon management. These include biochemistry, molecular and cellular biology, structural biology, genome science and ecology. In addition improvements in combustion to reduce carbon emissions require a fundamental understanding in chemical dynamics and theoretical chemistry and physics. Conversion of sunlight to energy requires an understanding in many areas of science, including photochemistry, photosynthesis, metabolism, and solid state physics. The search for increased efficiency in energy production and use requires fundamental knowledge in ceramics, metals, polymers, solid state chemistry, and condensed matter physics for materials that can withstand higher temperatures, have lower coefficients of friction, and are stronger and lighter. Enhanced recovery of fuel resources and of disposal of carbon dioxide requires a fundamental understanding of geometric, structural, and hydrologic properties of reservoirs and of multiphase, nonlinear transport of fluids in porous and fractured structures.

New research efforts supporting advances in low/no carbon energy technologies will provide the knowledge base for the development of advanced technologies to reduce carbon dioxide emissions. Many of the activities will impact the Office of Energy Efficiency and Renewable Energy (EE) and the energy and transportation industry by providing options for increasing efficiency in automobiles by reducing weight; for increasing efficiency in the use of electricity by increasing the efficiency of electric motors and generators with better magnets; for increasing efficiency in the transmission of electricity by using superconductors; and for reducing energy consumption in manufacturing with improved sensors, controls, and processes. Research will provide the knowledge needed to increase the use of renewable resources by understanding the metabolism of carbon dioxide and the metabolic pathways to the production of methane and other biofuels. Other aspects of the research program impact the Office of Fossil Energy (FE) by providing a foundation for effective and safe underground sequestration, new materials, a better understanding of combustion, and improved catalysts.

A climate change technology research and development program must address diverse aspects of the problem including: (1) carbon recycling; (2) improved efficiency in the use of fossil carbon energy sources; (3) new and improved noncarbon energy sources; and (4) carbon dioxide sequestration. The Department has long supported fundamental research in these categories and has particularly strong programs related to the first three. In the Materials Sciences program, research focuses on three areas: high-temperature materials for more efficient combustion, magnetic materials that reduce energy loss during use, and semiconductor materials for solar-energy conversion. In the Chemical Sciences program, research emphasizes atomic and molecular level understanding of chemical processes to enable predictive capability. One goal is reducing emissions of carbon dioxide through fundamental understanding of the chemistries associated with combustion, catalysis, photochemical energy conversion, electrical energy storage, electrochemical interfaces, and molecular specific separation from complex mixtures. In the Engineering and Geosciences program, research emphasizes carbon dioxide sequestration in subsurface geologic formations. The program will include research to: (1) understand the mechanical stability of porous and fractured reservoirs/aquifers; (2) understand multiphase fluid flow within the aquifers; and (3) understand the geochemical reactivity in relevant conditions. Finally, in the Energy Biosciences program, research emphasizes the biological process of photosynthesis, which is central to global carbon cycling.

Carbon Management Research Program

The Carbon Management Research Program emphasizes decarbonizing fuels and carbon sequestration through several elements. Ongoing CCTI research includes two new Centers for carbon sequestration. CSITE, the DOE Center for Research on Enhancing Carbon Sequestration in Terrestrial Ecosystems, supports research that investigates the enhancement of the natural terrestrial cycle and the potential environmental consequences of enhancing sequestration in the terrestrial ecosystem. The other center, DOCS, the DOE Center for Research on Ocean Carbon Sequestration, investigates enhancing the natural oceanic cycle and the efficacy and impacts of deep carbon dioxide injection. Other ongoing CCTI research includes the sequencing of one marine microorganism and three soil microorganisms that are crucial to affecting the carbon cycle. Other microbes will be selected for sequencing and structural biology will be used to help understand the role of biologically-driven sequestration reactions in the biosphere.

Enhancing the Natural Terrestrial Cycle. Research will identify ways to enhance carbon sequestration of the terrestrial through CO_2 removal from the atmosphere by vegetation and storage in biomass and soils. This includes the development of effective approaches to enhance potential sequestration in part through advances in the fundamental understanding of biological and ecological processes and the formation of soil organic matter in unmanaged and managed terrestrial ecosystems, including wetlands. It also includes efforts to understand ecological consequences of carbon sequestration. The research strategy focuses on those properties and processes of ecosystems for which alteration can offer significant potential for enhancing the net sequestration of carbon. Relevant technical areas of research include: (1) increasing the net fixation of atmospheric carbon dioxide by terrestrial vegetation with emphasis on physiology and rates of photosynthesis of vascular plants, (2) retaining carbon and enhancing the transformation of carbon to soil organic matter; (3) reducing the emission of CO_2 from soils cause by heterotrophic oxidation of soil organic carbon; and (4) increasing the capacity of deserts and degraded lands to sequester carbon.

Carbon Sequestration in the Oceans. The ocean represents a large potential sink for sequestration of anthropogenic CO_2 emissions. Two strategies for enhancing carbon sequestration are (1) the enhancement of the net oceanic uptake from the atmosphere by fertilization of phytoplankton with micro- or macronutrients, and (2) the direct injection of a relatively pure CO_2 stream to ocean depths greater than 1000 m. Sources of CO_2 for direct injection might include power plants, industries or other sources. The long term effectiveness and potential environmental consequences of ocean sequestration by either sequestration strategy are unknown. Research areas relevant to DOE's mission in carbon management include:

(1) environmental consequences of long term ocean fertilization; (2) effectiveness of ocean fertilization on a large scale; (3) environmental consequences of direct injection of CO_2 into the ocean in midwater or deep sea habitats; and (4) effectiveness of direct injection of CO_2 for carbon sequestration.

Sequencing Genomes of Microorganisms for Carbon Management. The Human Genome program has made significant investments in the technology that enables genome sequencing at rates previously unattainable. Capitalizing on these investments, the genomes of microbes that either produce fuels such as methane and hydrogen or that aid in carbon sequestration will be sequenced. This will enable the identification of the key genetic components of the organisms that regulate the production or capture of these gases. New research is being initiated to characterize key reaction pathways or regulatory networks in these microbes following the determination of their DNA sequence. Understanding more fully how the enzymes and organisms operate, we will be able to evaluate their potential use to produce, for example, methane or hydrogen from either fossil fuels or other carbonaceous sources, including biomass or even some waste products. Recently discovered “extremophile” organisms could be used to engineer biological entities that could ingest a feedstock such as methane, sequester the carbon dioxide, and give off hydrogen. Much of the living material responsible for natural carbon dioxide absorption, both on land and at sea, is microbial. Understanding how carbon dioxide “sinks” perform so we can enhance the ongoing natural processes may add powerful new measures to carbon management options.

Materials Science

The DOE Materials Sciences program supports basic research in condensed matter physics, metals and ceramics sciences, and materials chemistry. This research seeks to understand the atomistic basis of materials properties and behavior. Projects are supported in corrosion, metals, ceramics, polymers, glasses, ceramic matrix composites, catalytic materials, nondestructive evaluation, surface science, neutron and x-ray scattering, chemical and physical properties, and new instrumentation. Ultimately the research leads to the development of materials that improve the energy efficiency and environmental acceptability. These material studies affect developments in numerous areas, such as energy efficiency, waste storage and treatment, solar energy conversion, batteries and fuel cells, and stronger, lighter materials.

Materials sciences research seeks and supports basic understanding of materials whose properties are important to environmental quality. Research into the structure of materials enables projections of stability and reliability of vitreous and ceramic materials for the isolation and storage of radioactive wastes. Research in mechanical behavior and radiation effects includes work on the modeling of radiation damage and its effects on fracture toughness and load-bearing capacity of materials for use in high-radiation environments. Research in the area of engineering behavior seeks methods to synthesize new materials for waste storage and impacts efforts to minimize corrosion in hostile environments. The effort in materials chemistry encompasses work that impacts decontamination of surfaces of a wide array of materials used in weapons production activities, from stainless steel to concrete. Finally, fundamental experimental and theoretical research in condensed matter physics seeks understanding at the most fundamental level, from natural formation mechanisms to the role of impurities in material properties. Though not specifically directed toward environmental quality, all of these programs provide crucial supporting knowledge.

Structure of Materials

This activity supports basic research in the characterization and structure of materials; the relationship of structure to the behavior and performance of materials; predictive theory and modeling; and new materials. This activity provides four complementary electron beam microcharacterization user facilities to characterize localized atomic positions and configurations, chemical gradients, interatomic bonding forces, etc.

Mechanical Behavior and Radiation Effects

This research encompasses studies on the mechanical behavior of materials, including failure and fatigue resistance, fracture toughness and impact resistance, high-temperature strength and dimensional stability, ductility or deformability. These issues are critical to radiation effects, including understanding and modeling of radiation damage and surface modification using ion implantation. These activities relate to energy production and conversion, and radioactive waste storage, through the need for failure resistant materials that perform reliably in the hostile and demanding environments.

Physical Behavior

These activities support basic research in the physical behavior of materials, including aqueous, galvanic, and high-temperature gaseous corrosion and their prevention, phase equilibria and kinetics of reactions in materials in environments under extreme conditions, diffusion and the transport of ions in ceramics and glasses.

Neutron and X-ray Scattering

This activity supports basic research in condensed matter physics that makes use of neutron and x-ray scattering at major DOE user facilities. This research is aimed at a fundamental understanding of the atomic, electronic, and magnetic structure of materials and the effect of structure on the physical properties of materials.

Materials Chemistry

This activity supports basic research on the chemical properties of materials to understand the effect of chemical reactivity on the behavior of materials and to synthesize new chemical compounds and structures from which better materials can be made. The research is aimed at a fundamental understanding of the behavior of novel materials and structures. This activity includes research in solid state chemistry, surface chemistry, polymer chemistry, crystallography, synthetic chemistry, and colloid chemistry, which underpin environmental technologies, including energy efficiency research in fuel cells, batteries, membranes, catalysis, electrochemistry, and solar energy conversion.

Combustion Simulation and Modeling

The program supports research in simulation and modeling, providing detailed understanding of combustion processes to accelerate the development, characterization, and validation of design tools for advanced combustion. Understanding combustion chemistry, fluid dynamics with turbulence, the prediction of combustion device performance, particularly the emission characteristics of combustion devices is relevant to increased energy efficiency.

Materials Science Research

Materials science research is a key component of the EMSP. Nearly a dozen projects are studying the chemical and structural properties of potential waste storage materials. Several of these projects are aimed at understanding the mechanism of radiation effects on glasses that are to be produced in the vitrification of long-lived radioactive wastes. Little is known about the effect of exposure to radiation over long time periods on glassy materials, and these projects are intended to determine the potential for breakdown of glasses through, for example, crystallization or phase separation. Studies are also being carried out on the synthesis and properties of potential crystalline waste storage forms. Several projects are devoted to the study of surfaces to gain understanding of corrosion processes or to determine potential means of cleaning contaminated surfaces.

Scientific User Facilities

The Department of Energy has a long-standing commitment to the operation of major user facilities open to scientists and technologists from the academic, industrial, and government sectors. Indeed the Department's system of scientific user facilities is the largest of its kind in the world.

The most important of these facilities for the environmental field is the William R. Wiley Environmental Molecular Sciences Laboratory (EMSL), located at Pacific Northwest National Laboratory (PNNL) in Richland, Washington. As a national scientific user facility, the mission of the EMSL is to provide advanced and unique resources to scientists engaged in research on critical problems in the environmental molecular sciences and to educate young scientists in the molecular sciences to meet the demanding environmental challenges of the future. As a research organization, the EMSL seeks to attain an understanding of the physical, chemical, and biological processes needed to solve critical environmental problems and to advance molecular science in support of the DOE's long-term environmental mission. The EMSL is noteworthy for its unique instrumentation in high field mass spectrometry, high field nuclear magnetic resonance spectrometry, laser spectroscopy, computational chemistry and related fields, and for its emphasis on collaborating with scientists at other institutions in applying this instrumentation to solving environmental problems. EMSL scientists are active in the EMSP, with funding across the range of fields from analytical chemistry through bioremediation to geophysics. These projects emphasize research directed at solving problems in the high level radioactive waste and the subsurface/vadose zone EM need areas.

Other DOE scientific user facilities also provide experimental capabilities that are beyond the scope of those found in laboratories of individual investigators. Synchrotron radiation light sources, high-flux neutron sources, electron beam microcharacterization centers, and other specialized facilities enable scientists to carry out experiments that could not be done elsewhere. These facilities are planned in collaboration with the scientific community and are constructed and operated in support of forefront research in areas important to the Department as well as to researchers in programs of other agencies and the private sector. These facilities are used by researchers in materials sciences, chemical sciences, earth and geosciences, environmental sciences, structural biology, superconductor technology, and medical research and technology development. The facilities are open to all qualified scientists from academia, industry, and the federal laboratory system whose intention is to publish in the open literature. The four synchrotron light sources are especially important for environmental studies, as they offer capabilities for characterizing the actual chemical form of major contaminants such as plutonium and technetium in unmodified environmental samples. Several EMSP projects are making extensive use of the synchrotrons. One grant funded development of a beam line at the Advanced Photon Source at the Argonne National Laboratory that will be used for a wide range of environmental studies including characterization of subsurface and tank waste samples. The synchrotron light sources will also be used for the study of properties of materials being considered as waste storage forms.

Appendix
Budget Profiles

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Budget Profiles

Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
High-Level Waste	**54,760**	**59,530**	**61,952**
Safe Waste Storage	5,955	6,180	8,941
Waste Retrieval	12,715	11,345	18,643
Waste Pretreatment	12,736	16,110	17,182
Waste Immobilization	11,150	10,360	10,134
Tank Closure	2,717	1,007	2,036
Directed Science	9,487	14,528	5,016
Mixed/Low-Level/Transuranic Waste	**37,224**	**34,965**	**37,842**
Waste Characterization	4,978	5,372	4,004
Transuranic Waste Transportation	1,105	1,663	2,612
Waste Handling	6,049	4,748	7,412
Alternatives to Incineration	3,146	2,438	3,354
Off-Gas Monitoring and Filtration	8,942	7,766	4,568
Mercury Contamination	1,290	0	0
Unique Wastes	2,012	5,443	6,052
Waste Stabilization	565	0	0
Directed Science	9,137	7,535	9,840
Spent Nuclear Fuel	**48,472**	**33,740**	**36,319**
Data Acquisition and Validation	1,080	1,600	2,220
Treatment or Conditioning	44,391	28,100	30,484
Packaging for Dry Storage	900	1,690	1,780
Directed Science	2,101	2,350	1,835
Nuclear Materials	**25,264**	**22,201**	**24,399**
Performance Testing and Qualification for Repository Disposal	4,410	4,153	3,127
Stabilization	5,246	4,085	6,036

Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Packaging, Transportation & Storage	3,958	3,082	5,630
Site/Technology Support	9,509	9,100	9,079
Directed Science	2,141	1,780	526
Disposal	**59,163**	**47,218**	**44,619**
Core Science	26,348	21,026	19,869
Design and Engineering	16,219	12,947	12,235
Total System Performance Assessment	13,059	10,421	9,847
R&D Support	3,537	2,824	2,668
Environmental Remediation	**77,526**	**58,901**	**58,810**
Identify	9,418	6,085	6,717
Contain	6,151	5,603	5,178
Remediate	18,364	21,027	17,843
Remove	3,261	4,306	1,862
Validate	2,988	4,289	5,603
Directed Science	37,344	17,591	21,607
Deactivation and Decommissioning	**30,923**	**32,686**	**21,874**
Reactor Facilities	9,157	8,419	3,645
Radionuclide Separation Facilities	9,322	10,189	9,462
Fuel and Weapons Component Fabrication Facilities	5,742	8,627	5,265
Laboratory Facilities	4,574	0	0
Directed Science	2,128	5,451	3,502
Total	**333,332**	**289,241**	**285,814**
SBIR Support*	**3,566**	**4,565**	**2,175**
Total	**336,898**	**293,806**	**287,989**

* Funds from the EQ R&D Portfolio provided to Small business Innovative Research