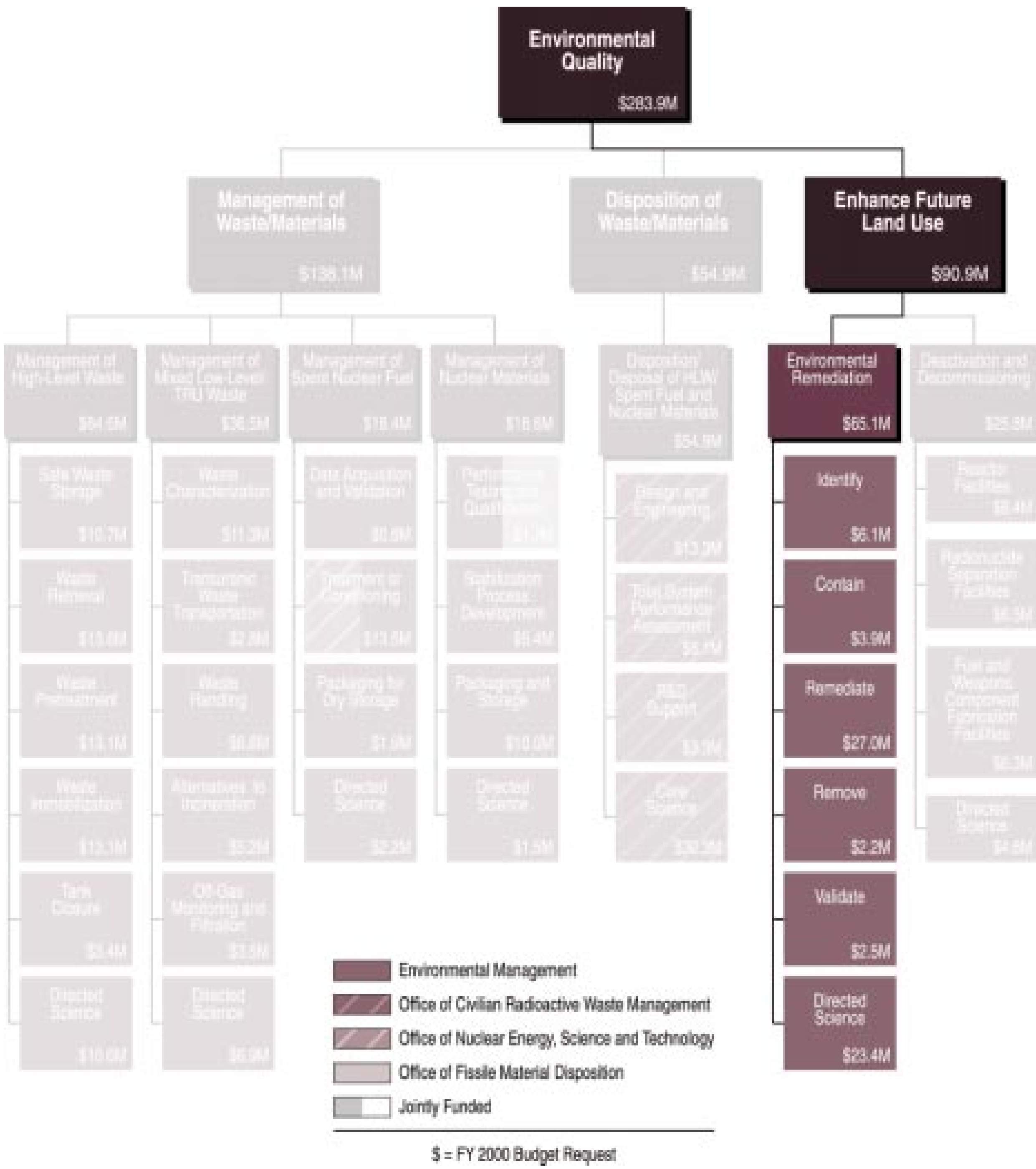
Chapter 8
Environmental Remediation



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.

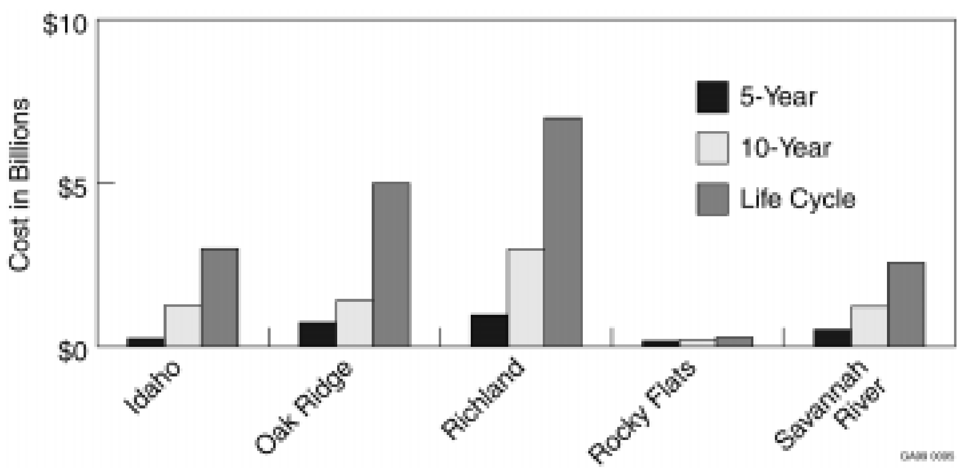


Figure 8-1. Five-year, ten-year, and life-cycle environmental remediation costs.

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.
- 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

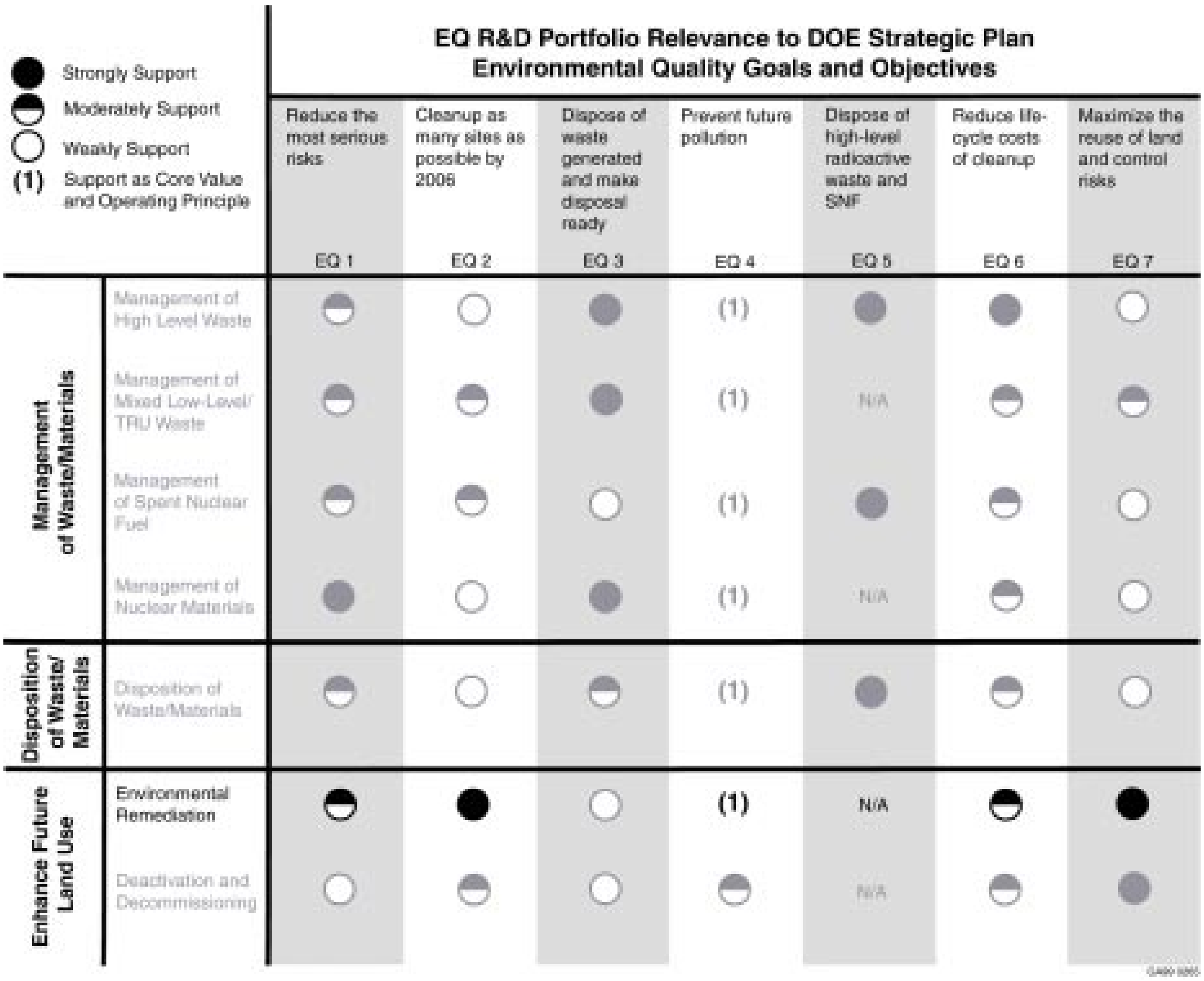


Figure 8-2. Relevance of environmental remediation R&D investments to Environmental Quality goals and objectives.

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 consistuents, including ploycholorinated 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 aggreements 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. Comtamination 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.

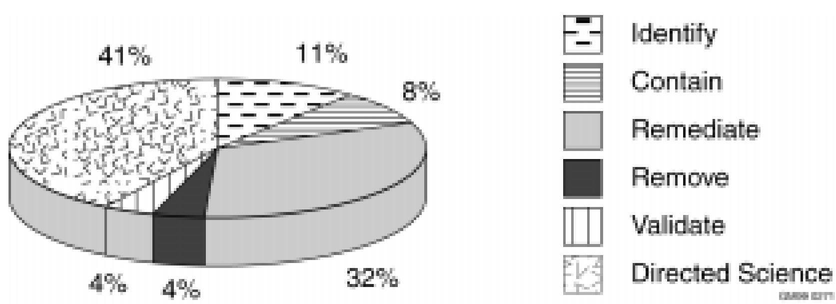


Figure 8-3. Cumulative investment in environmental remediation areas over 3 years (FY 1998–FY 2000).

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 Soil Heating and the Thermally Enhanced Vapor Extraction System.

- 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: FY98-$74.8M, FY99-$82.3M, FY00-$65.1M

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: FY98-$9.5M, FY99-$9.0M, FY00-$6.1M

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 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, pending the results of a peer review, anomaly-versus-offset (AVO) Seismic Reflection technology for the non-invasive determination location/distribution of free phase DNAPLs.

Contain

Budget: FY98-$8.0M, FY99-$5.4M, FY00-$3.9M

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 to be determined (possibly Brookhaven National Laboratory [BNL] or Hanford). 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 a site to be determined. In situ vitrification, utilizing a novel approach that begins below the targeted waste and melts upward, will be demonstrated.

Remediate

Budget: FY98-$21.2M, FY99-$22.4M, FY00-$27.0M

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 may be installed at 3 to 4 other Rocky Flats SMWUs in FY2000 if the performance of the Reactive Barrier is successful. Performance verification will also be completed for the Geoflow Treatment System installed at Savannah River Site (SRS). 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 Reduction (of Chromate) will be demonstrated at Hanford. An ACT*DE*CON will be deployed at Mound and will include the testing of NTS soils at Mound to investigate a possible second deployment at NTS.

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 *Accelerating Cleanup- Paths to Closure* 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 will be demonstrated at a DOE site contaminated with TCE and other DNAPLs and the system will be deployed at additional DOE sites following a successful demonstration.

Electro-osmosis (Lasagna™) will be deployed at a second site and a surfactant enhanced aquifer remediation will be deployed at the Idaho National Engineering and Environmental Laboratory. 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: FY98-$4.1M, FY99-$2.3M, FY00-$2.2M

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 will be deployed at Sandia National Laboratories (SNL), Pantex, NTS, and FEMP.

Validate

Budget: FY98-$3.1M, FY99-$4.3M, FY00-$2.5M

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: FY98-$29.0M, FY99-$38.8M, FY00-$23.4M

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.

Between 1998 and 2000, over 100 directed research projects will be funded for a total amount of $91 million. This funding includes over $34 million in research to address issues related to health, ecology and risk, and between 20 to 30 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 provide fundamental data and models for predicting plutonium speciation and environmental behavior that will allow evaluation of the many processes proposed for remediation of plutonium-containing DOE wastes.

- *Analytical Chemistry and Instrumentation:* Research addresses biomedical instrumentation, laser ablation techniques, and sensors and techniques. Develop or improve instrumentation and techniques to assist in characterizing the contamination at DOE sites. The 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. 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:* The research provides knowledge in the areas of bioengineering and bubble mechanics and sonification. Basic 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:* The research includes studies in colloidal chemistry and transport and sorption/desorption. There are thirteen 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:* The research will improve the understanding of subsurface imaging. Basic 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:* The 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:* The 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 fifteen 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 research area is 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.

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 expects to fund approximately $34.4 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.

In 1999, a program will be initiated to study the effects of exposures to low doses of radiation. It is expected that one to fifteen additional awards will be made. 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.

Budget Summary Table

(Dollars in thousands)

Research Areas	FY 1998 Appropriated	FY 1999 Request	FY 2000 Request
Identify	9,461	8,987	6,080
Contain	7,984	5,426	3,871
Remediate	21,167	22,445	27,003
Remove	4,080	2,320	2,247
Validate	3,075	4,298	2,479
Directed Science	28,992	38,833	23,396
Total	**74,759**	**82,309**	**65,076**