U.S. Department of Energy
Office of Science
Office of Biological and Environmental Research
Environmental Remediation Sciences Division (ERSD)

Strategic Plan

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Foreword

The ERSD Strategic Plan has benefited from excellent discussions with and reports from the Biological and Environmental Research Advisory Committee (BERAC) subcommittees on the Natural and Accelerated Bioremediation Research (NABIR) program and on ERSD over the past two years. Much of what comprises the plan is based upon the results of two workshops held in the summer and fall of 2002. Attendees included a broad spectrum of the environmental scientific community (from national laboratories and universities), and Department of Energy (DOE) program managers from the Office of Science, the Office of Environmental Management, and the Office of Civilian Radioactive Waste Management. Representatives from other federal agencies including the National Science Foundation, Department of Defense and Environmental Protection Agency, as well as organizations such as the National Academy were active workshop participants. In addition, reports prepared by the National Research Council's Board on Radioactive Waste Management and comments from the BERAC ERSD subcommittee were extremely valuable to the planning process. Finally, former ERSD staff members Henry Shaw and Anna Palmisano have made major contributions to the writing of this plan. On behalf of the Office of Science, I would like to thank all the contributors to this strategic plan for the Environmental Remediation Sciences Division.

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Executive Summary

The Environmental Remediation Sciences Division (ERSD) was formed in July of 2002 in the Department of Energy's (DOE) Office of Biological and Environmental Research (BER) under the Office of Science. The Division was created to support research that provides the fundamental scientific knowledge needed to address challenging environmental problems that impede the remediation of contaminated environmental sites and treatment of stored waste at DOE sites. To this end, two programs from the DOE Office of Environmental Management, the Environmental Management Sciences Program (EMSP) and the Savannah River Ecology Laboratory (SREL); have been transferred and combined with two closely related programs in the Office of Science, the Natural and Accelerated Bioremediation Research Program (NABIR) and the Environmental Molecular Sciences Laboratory (EMSL). The four programs were brought together in one Division to increase their effectiveness through coordination and integration of the research supported in the individual programs. This Strategic Plan was developed to provide an overall Division strategy that articulates cross-cutting goals and a vision for program integration.

The ERSD mission is *to advance the fundamental science leading to solutions to currently intractable problems or to breakthrough strategies for the remediation of the DOE sites and other DOE energy and environmental missions.*

ERSD has four overarching goals that specifically address this mission:

- Develop an improved understanding of the fate and transport of doe relevant contaminants in subsurface and surface environments, including the role of microbes and plant life;
- Provide the scientific foundation for the development of robust, affordable characterization tools for in situ assessment and monitoring of contaminated sites, as well as for contained or immobilized waste;
- Provide the scientific foundation to enable in situ remediation of contaminated soils and groundwater or other contaminated media; and,
- Support basic research leading to cost-effective and safe management and treatment of stored radioactive wastes.

These goals can only be met through sustained, integrated research ranging from laboratory to field scales. The ERSD uses Field Research Centers (FRCs) as tools to meet these goals. The FRCs conduct comprehensive, integrated, long-term field studies of topics with broad applicability to DOE. Research conducted at FRCs involves interdisciplinary teams of researchers who share results on a regular basis and are closely tied to experimental and modeling efforts.

By closely coordinating research conducted in the four programmatic areas and integrating results across a range of scales (from laboratory to field), ERSD works to advance the basic science needed to address DOE's environmental remediation issues.

1. Introduction

During World War II and continuing to the present, the United States government created a network of industrial facilities for development, production, and testing of nuclear weapons. The activities of DOE and its predecessor agencies at these facilities resulted in radioactive and chemical wastes, as well as contaminated facilities and materials, at more than 113 separate sites in 31 states and Puerto Rico. The large majority of environmental problems and costs are located at the major production sites: the Hanford site in Washington State, the Idaho National Engineering and Environmental Laboratory, the Oak Ridge Site in Tennessee, and the Savannah River Site in South Carolina. The problems at these sites include large areas of contaminated soils and groundwater, complex radioactive stored wastes, corroding spent nuclear fuels, buried wastes, and hundreds of contaminated facilities. Contaminants include radionuclides, organic chemicals, and toxic metals. The DOE is responsible for environmental remediation of all these sites, and in 1989, formed the Office of Environmental Management to carry out this responsibility.

No remediation[1] effort of this nature or magnitude has ever been attempted. In addition, effective and affordable solutions to environmental contamination problems frequently do not exist, whether the contaminants are radionuclides, toxic metals, or organic compounds. For example, scientists have only a crude understanding of how contaminants behave in nature—how they interact with minerals, plant materials, and soil microbes, and how they move in groundwater, surface waters, or other pathways of human and environmental exposure. Limitations to our understanding of environmental processes mean that we are often ignorant of the uncertainties associated with our cleanup targets and standards. In addition, there are no proven technology options to treat large portions of the complex and poorly characterized stored radioactive wastes at these sites.

From a scientific point of view, on the other hand, the scientific community is at a point where it can begin to address complex environmental issues in a rigorous and comprehensive manner—the same set of scientific tools that are revolutionizing many fields of science, including biology, materials science and medicine, are also applicable to many environmental issues. These include the physical science tools of spectroscopy and microscopy developed over the last few decades that allow scientists to investigate phenomena at the molecular level. In addition, the computational community is learning how to address the complexity of real phenomena, and adequate computer power now exists to do so. Finally, the scientific community has realized that natural systems do not reside neatly within traditional individual scientific disciplines, and that researchers must therefore work across disciplinary boundaries to make progress. In addition, the scientific community is now appreciative of the importance of life in the environment—with a specific appreciation for the role that microbes can play in environmental processes. Significant advances in microbial genomics and biology are providing a much more complete picture of these

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[1]For the purposes of ERSD, we are using the term "remediation" in a broad sense, to include actions taken to cleanup contaminated soils and waters, as well as treatment of contained wastes.

processes. By combining these new tools and disciplines with the more traditional discipline of ecology, remediation decisions can be based not only on more accurate estimates of risk to human health, but also on risk to the environment and its inhabitants.

The fundamental understanding developed in ERSD programs, although focused on the DOE's environmental remediation problems, helps to provide solutions for environmental problems throughout the nation and worldwide. Hazardous wastes in the environment from many sources threaten human health and the environment. While some of the fundamental science relevant to remediation of the DOE sites may be unique to the DOE (*e.g.,* the chemistry of high-level radioactive wastes—HLW), there are substantial commonalities with other environmental issues. For example, the basic processes that control the fate and transport of contaminants in the near-surface and subsurface environment are common to problems involving agricultural pollution, the fate of industrial effluents, acid mine drainage, the safety and quality of drinking-water supplies, and a host of other issues related to the aqueous transport of chemicals. Similarly, the societal context in which difficult and costly DOE remediation decisions must be made has many aspects in common with decisions dealing with other environmental hazards, as well as other agencies and organizations.

2. Environmental Remediation Sciences Division

The Environmental Remediation Sciences Division was created to address environmental issues using powerful new scientific tools.

> *The ERSD mission is to advance the fundamental science leading to solutions to currently intractable problems or to breakthrough strategies for the remediation of the DOE sites and other DOE energy and environmental missions.*

ERSD programs focus on those fundamental issues where basic research can have significant impact on characterization, assessment, cleanup and stewardship at DOE sites. The scientific results provided by ERSD form the basis for improving remediation technologies and for making better cleanup decisions in the future. To this end, ERSD encourages and supports excellent theoretical, laboratory, and field-based research. Integrated studies are supported that involve a range of scientific disciplines, including experimental studies in the physical, chemical and biological sciences, as well as studies in environmental engineering, computational science and simulation/modeling.

The Division emphasizes an interdisciplinary, collaborative approach to stimulate scientific progress in a field that is often constrained by traditional disciplinary boundaries. ERSD provides research funding to universities, national laboratories, industry, and other research institutions. Programs within the Division support high quality research that is well coordinated with related activities in both the public and private sectors. In addition, ERSD fosters dialogues among researchers and the federal and contractor staff charged with cleanup operations to ensure that ERSD research leads to effective new technologies and provides the appropriate scientific data to inform environmental cleanup decisions.

The programs that have been combined to form ERSD have contributed significantly to the DOE cleanup effort, as well as to an improved understanding of environmental science.

The **Environmental Management Science Program** (**EMSP**) supports science that focuses directly on the DOE cleanup mission and has resulted in significant cost avoidance and provided the basis for technologies where none existed before. **The Natural and Accelerated Bioremediation Research** (**NABIR**) program is leading the Nation in our understanding of microbial behavior in subsurface environments and how microbes interact with radionuclide and toxic metal contaminants. This could lead to new *in situ* remediation strategies, as well as revolutionize our thinking about life in the environment. **The Environmental Molecular Sciences Laboratory** (**EMSL**) is a national scientific user facility that provides and develops leading edge experimental and computational tools for environmental research. EMSL makes these resources available to the general scientific community, and many scientists funded by the EMSP and NABIR programs have made extensive use of EMSL resources. The **Savannah River Ecology Laboratory** (**SREL**) has a long history of studying the impacts of DOE activities on the ecosystem and environment at the Savannah River Site. The challenge for ERSD is to focus and integrate the science in these complementary programs to optimize and deliver results that can be used by technology developers, decision-makers and the public. Details about each program can be found on the web (see Section 9).

3. Division Goals

ERSD has four overarching goals that specifically address the stated mission of the Division. These goals guide the Division's future scope and directions. They reflect input from the scientific and stakeholder community through planning workshops as well as reports from the DOE and National Research Council. The Division goals are to:

- Develop an improved understanding of the fate and transport of DOE relevant contaminants in subsurface and surface environments, including the role of microbes and plant life;
- Provide the scientific foundation for the development of robust, affordable characterization tools for in situ assessment and monitoring of contaminated sites, as well as for contained or immobilized waste;
- Provide the scientific foundation to enable in situ remediation of contaminated soils and groundwater or other contaminated media; and,
- Support basic research leading to cost-effective and safe management and treatment of stored radioactive wastes.

It is anticipated that results from ERSD funded research in these four areas will contribute significantly to long-term stewardship of DOE sites and reduce risks to human health and the environment. For example, development of tools for long-term monitoring and predictive models of contaminant fate and transport will be critical for long-term stewardship, and also will provide valuable information for assessing and modeling potential risks to humans and the environment.

Goal 1: Develop an improved understanding of the fate and transport of DOE relevant contaminants in subsurface and surface environments, including the role of microbes and plant life.

Fundamental research on contaminant fate and transport is needed to improve the accuracy of predictions of the movement of contaminants through subsurface or surface sediments and trophic levels. To achieve this goal, results from a wide range of scientific disciplines need to be integrated. Ersd supports research to develop an understanding of the key processes in complex environmental systems involving multiple spatial and temporal scales.

Problem Statement

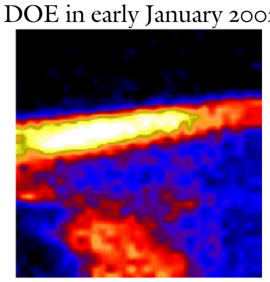
The importance of developing improved capabilities for predicting the fate and transport of contaminants through the environment has been articulated in numerous reports on research needs for DOE's environmental cleanup (*e.g.,* DOE 2000, National Research Council 1999, 2000, 2001a). The lack of understanding of the many processes that affect contaminant transport in the environment has led to the use of "bounding" models that establish a maximum (rather than realistic) estimate for the hazard. Thus, the hazard may be vastly overestimated, and cleanup efforts based on such estimates may be unnecessarily costly. More realistic predictions of contaminant transport will enable more cost-effective cleanup actions and better informed choices among remediation alternatives. Realistic predictive models are also the key to effective management of ongoing active remediation, as well as long-term stewardship of sites.

Basic research—laboratory- and field-based experimental research as well as theory-based research will result in a more complete understanding of the biological, chemical, and physical processes that control contaminant movement. This, in turn, will lead to improved predictive models for contaminant transport. Because the processes controlling contam-

Improved Reactive Transport Models Support Regulatory Decisions for Corrective Actions at the Hanford Tank Farm.

A team of EMSP-supported university and national lab investigators has developed improved conceptual and numeric models for contaminant migration. These models were used to support regulatory decisions regarding corrective actions for the Hanford S-SX tank farm, where 90 kCi of ^{137}Cs has leaked from single-shell tanks.

The team first characterized the fundamental geochemical processes controlling ^{137}Cs migration from laboratory to field scale using pristine and contaminated Hanford sediment. The highly radioactive samples were analyzed using synchrotron x-ray radiation at two DOE-supported user facilities (Stanford Synchrotron Radiation Laboratory and Advanced Photon Source) to provide insights on chemical speciation and location of the Cs within the mineral grains. Next, the mineralogical properties of Hanford sediment and complex aqueous chemistry of high-level wastes were incorporated into reactive transport models that provided good descriptions of field scale behavior. The results from these studies were incorporated as an appendix to the River Protection Program Field Investigation Report for the S-SX tank Farm, which was submitted to Tri-Party Agreement regulators by DOE in early January 2002.



X-ray image (100-μm across) showing Cs concentration (color intensity is proportional to concentration) in a thin section of a biotite grain from Hanford. Cs is preferentially bound within internal structural channels.

inant transport operate over spatial and temporal scales spanning many orders of magnitude, new experimental and computational strategies must be developed that can deal with the resulting scaling issues. Furthermore, even the best models are of limited use in decision-making unless the results are accompanied by an estimate of the reliability and uncertainty of the models' predictions. New approaches are needed to estimate uncertainty across relevant spatial and temporal scales.

In addition to their use as predictive tools, models play an important role in helping to identify key processes affecting contaminant fate and transport in complex environments. It is impossible to incorporate every chemical, biological, and physical process, from the molecular to the kilometer scale, in a subsurface contaminant transport model. Nevertheless, attempting to construct coupled models that incorporate as much detail as possible is essential for making progress in understanding complex environmental systems. It is only through these efforts that the interactions among processes can be explored and understood. Numerical simulations also provide a framework for integrating disparate types of information from a wide range of disciplines.

Although models for predicting contaminant fate and transport have existed for decades, few, if any, of these models have been able to treat the coupled physical, chemical, and biological interactions that actually control contaminant transport. In particular, the importance of microbes in contaminant transport and attenuation in the environment is only beginning to be appreciated. The availability of molecular tools and modern genomics greatly enhances the understanding of the role of microbes in contaminant fate and transport.

Research Areas

To address the needs identified above, ERSD supports research in the following areas:

- Integrated geochemical, biological, hydrological, geophysical, and ecological studies aimed at defining the fundamental mechanisms controlling contaminant fate and transport. Such interdisciplinary studies can be used to test new conceptual and computational models;
- Biogeochemical understanding of the complex relationships between microbes and the environment;
- Molecular level understanding of important processes controlling the fate and transport of contaminants in subsurface and surface sediments and between trophic levels;
- [2] [Methods to integrate data collected at different spatial and temporal scales and to incorporate such data into conceptual models];
- [Methods for scaling, in both space and time, of chemical, biological, and physical processes relevant to contaminant fate and transport. This might include models

[2] Research areas that are denoted in brackets represent areas where ERSD has not yet sponsored significant amounts of research and may require additional or redistributed funds to do so.

representing contaminant fate and transport at a scale larger than the one in which observations and measurements are made];

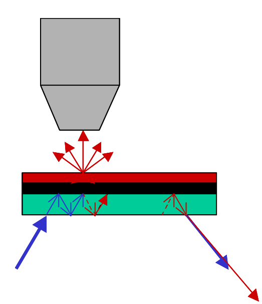
- [Research leading to the identification of 1) key measurements required to verify models and understand system behaviors, 2) the spatial and temporal resolution required, and 3) the extent to which surrogate data can be used in model verification];
- [Methods for quantifying uncertainties in model predictions].

***Goal 2:** Provide the scientific foundation for the development of robust, affordable characterization tools for in situ assessment and monitoring of contaminated sites, as well as for contained or immobilized waste.*

Research in ERSD provides the basis for new techniques for locating contamination and for characterizing and monitoring subsurface properties that affect contaminant fate and transport. Also included is the characterization of contained wastes to support treatment decisions, and monitoring for process control. Contaminants of DOE interest include radionuclides, toxic metals, and organic species.

Spectroelectroelectrochemical Sensors for Monitoring of DOE Site

An EMSP-sponsored collaboration is designing and implementing a new sensor technology that offers unprecedented levels of specificity needed for analysis of complex chemical mixtures such as those found at DOE sites nationwide. The approach combines three modes of selectivity (electrochemistry, spectroscopy, and selective partitioning) into a single sensor to substantially improve selectivity. The sensor has been successfully demonstrated on ferrocyanide in Hanford tank waste. Current work focuses on development of a similar sensor for pertechnetate, TcO_4^-. This sensor would be used as an environmental monitor at DOE sites with radioactive waste. The project is a collaboration between the Department of Chemistry at the University of Cincinnati and Pacific Northwest National Laboratory.



Spectroelectrochemical sensor in fluorescence mode.

Problem Statement

Numerous recent studies have identified the need for new methods for locating and characterizing contaminants in the subsurface, and for characterizing the subsurface itself (DOE, 2000, 2001a; National Research Council, 2000, 2001a). At many sites, the location of subsurface contaminants is poorly known, and available characterization methods do not adequately meet site needs. Direct methods for subsurface characterization (*i.e.*, sampling from boreholes), are expensive, limited in range, and can potentially provide routes for wider dispersal of contaminants. Accurate characterization and assessment methods are needed to perform field research and to design, implement and monitor effective remedial strategies. Techniques are needed to track the location of contaminants, and to characterize contaminants in terms of concentration, speciation, and distribution. In addition to characterization techniques, improved methods are needed to determine the chemical, physical and biological properties of the environment that affect contaminant fate and transport.

Improved techniques for characterization of radioactive wastes are a priority area, especially for wastes stored in underground tanks at the Hanford site, where the age of the tanks and chemical variation of the contents make it nearly impossible to predict waste behavior. Our ability to predict waste behavior is vital at every step in HLW treatment—from retrieval to pretreatment, and stabilization.

Cost-effective approaches are needed to support long-term monitoring at sites to assess the success of the selected remedial strategy. For example, techniques are needed to reliably monitor stored immobilized waste for long periods, as well as radionuclides and toxic metals that have been immobilized in subsurface environments. Such approaches will require remote, autonomous sensors with a high degree of sensitivity and specificity.

Research Areas

To address the needs identified above, ERSD supports research in the following areas:

- Techniques (including novel sensors) to characterize the key chemical, physical, and biological properties that affect contaminant fate and transport.
- Basic research leading to improved real time, remote or minimally invasive techniques for locating contamination in situ and for determining the physical/chemical properties of those contaminants. This includes detailed characterization of the migration of contaminant plumes;
- Basic research into characterization of stored radioactive wastes, including improved analytical methods for determining and measuring those factors that will have the potential to impact waste management operations;
- [Developing a basis for long-term monitoring of contaminated sites and immobilized wastes, capable of reliable unattended operation in remote locations over a decade or more. This would include methods for detection of failure of stabilized waste likely to be stored in place at DOE sites, for sites that have been selected for natural attenuation or in situ treatment].

GOAL 3: Provide the scientific foundation to enable in situ remediation of contaminated soils and groundwater or other contaminated media.

In some cases, contaminants are already widely dispersed in subsurface or soil environments at low concentrations. Discharge of these contaminants to groundwater or receiving water bodies must be prevented or minimized. Naturally-occurring microorganisms have abilities to remediate contaminants through reduction and precipitation (in the case of toxic metals and radionuclides) or through biodegradation to benign substances (in the case of organics). Plants and associated root microorganisms can be exploited to help remediate contaminated soils. Bioremediation by microorganisms and plants typically occurs at fairly slow rates, so there may be a need to accelerate the process by addition of nutrients. Though the focus will be on widely dispersed contaminants, ERSD also will address contaminants that remain concentrated in the environment, such as Dense Nonaqueous Phase Liquids (DNAPLs), that are difficult to locate or remediate. In addition to providing the basis for in situ remediation strategies, ERSD also will evaluate the potential ecological impacts of such strategies.

Problem Statement

Even when the location and nature of subsurface contamination are known, the DOE currently has few alternatives for remediation of dispersed contaminants in soils, subsurface sediments, and groundwater. The usual baseline solutions are limited to excavation, pump and treat methods, or capping and leaving in place. Excavation and pumping methods are often not financially feasible given the huge volumes of contaminated soil and groundwater that require remediation; the depth of the contaminated aquifer also may preclude the pump and treat approach. Capping, without a scientifically defensible basis for predicting the long-term fate of the system, may at best be a temporary measure. Furthermore, both the excavation and capping options have serious environmental consequences. As a result, the DOE faces a large number of problems that currently lack feasible solutions. There is a clear need for the development of novel technologies that can overcome or circumvent the obstacles that currently make these problems intractable. Though radionuclide contamination is unique to DOE (in the U.S.), contamination of soils and subsurface sediments by other toxic metals and organic species is a major issue in the United States and around the world.

Research Areas

To address the needs identified above, ERSD supports research in the following areas:

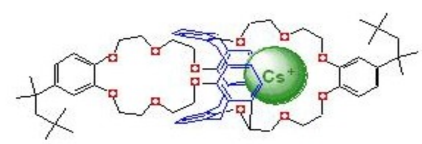
- Bioremediation strategies that use naturally occurring subsurface microorganisms to immobilize toxic metals and radionuclides, thereby limiting their transport in the environment;
- Biogeochemical processes affecting the speciation, bioavailability and transformation of contaminants. This includes understanding the rates and kinetics of both biotic and abiotic reactions in situ. This research should lead to an improved understanding of natural attenuation as well as accelerated remediation approaches;
- Phytoremediation research addressing the mechanisms of uptake and transformation of contaminants; incorporation into plant biomass; and the role of rhizosphere microorganisms in enhancing these processes;
- [Predictive models of long-term metal and radionuclide immobilization in the subsurface];
- [Potential ecological impacts of remediation approaches under investigation];

- [Design and evaluation of new materials for use in reactive and passive membranes, barriers, and caps.]

GOAL 4: Support basic research leading to effective and safe management and treatment of stored radioactive wastes.

Research addressing this goal will lead to 1) improved understanding of the complex chemistry of high-level radioactive wastes; 2) novel techniques for separating wastes into components to facilitate treatment; and 3) new treatment and stabilization options (including waste forms suitable for disposal) for radioactive wastes. While the focus of this goal is on HLW, much of what is learned also may be relevant to other complex radioactive waste and spent nuclear fuel problems.

Fundamental Studies Enable the Cleanup of Nuclear Waste at Savannah River



Calix[4]arene-bis(*tert*-octylbenzo-crown-6)
"BOBCalixC6"
(As complexed with Cs + ion)

Research on chemical separation methods sponsored by the EMSP led to the development of the Caustic-Side Solvent extraction (CSSX) process, which the DOE recently selected for use at the Salt Processing Facility at the Savannah River Site. The process, developed at Oak Ridge National Laboratory, will be used to separate and concentrate radioactive cesium (^{137}Cs) present in liquid high-level waste. Approximately 34 million gallons of such waste are stored in tanks at the Savannah River Site, which is processing the waste into glass "logs" suitable for disposal in a deep geologic repository.

Problem statement

One of the most costly and challenging tasks that the DOE faces is the treatment and disposal of high-level radioactive wastes (HLW) stored in large underground tanks (DOE 2000; NRC 2001b). A better understanding is needed of the complex chemistry of these wastes, which are generally composed of highly concentrated, alkaline solutions and precipitated solids. Because of the intense radiation associated with these wastes, characterization of the chemistry and physical properties of both tank wastes and process streams is challenging, and must be done remotely. Better methods for providing real-time characterization, particularly those that can operate in situ, are needed for all phases of waste processing, from storage and tank retrieval to handling to treatment.

The development of new techniques for separating wastes into components that are more easily treatable has the potential for dramatically reducing or avoiding costs, reducing risks, and improving final waste forms. For example, development of novel separations media that also serve as the final waste form after the separation would reduce the number of major processing steps, minimize creation of low level waste during processing, and potentially save billions of dollars. Thus, there are strong incentives for investing in research that could lead to alternative waste processing/treatment options. The knowledge and general principles arising from ERSD research in separations chemistry will be applicable to development of other types of treatment technologies.

A major issue is the retrieval of wastes from the tanks and closure of the tanks once the waste has been retrieved. Currently, the lack of characterization of the waste makes retrieval a trial and error process that has high risk and cost. Improving this process requires a fundamental understanding of the chemistry of the tank contents, models for predicting changes in waste chemistry over time, and models for predicting the reliability of the tanks structures. In many cases, a significant amount of waste will not be retrievable. In the closure process, the risks posed by these "heels" and methods to stabilize them in situ will need to be developed.

Another problem, one in which great cost savings could be realized, is the stabilization of the low-level waste fraction of HLW. Currently, concretes or glasses are the baseline approaches. However, there are opportunities to improve both the waste loading and performance of these materials, resulting in large volume and cost reductions.

New experimental and computational tools that predict how radionuclide chemical forms change over time in both complex waste mixtures and in final waste forms are needed for more accurate predictions of the long term stabilization of HLW. The results of this work could apply to a number of radioactive waste types and sources.

Research Areas

To address the needs identified above, ERSD supports research in the following areas:

- Fundamental laboratory studies and development of models to predict the chemistry of HLW solutions and associated solids;
- Tailored separations processes for reducing HLW volume, toxicity, and improving waste form quality;
- Novel physical-chemical approaches to waste treatment and stabilization for HLW, as well as other waste streams, including chemical or thermal destruction of organics and immobilization or containment of radionuclides;
- [Design and characterization of novel waste forms that are tailored to specific waste streams, that can accept high loadings of waste, and that have reliable long-term performance under disposal conditions];
- [Fundamental studies leading to in situ stabilization of waste that will remain in storage tanks after tank closure (i.e., heels).]

Timeline of ERSD Deliverables

For each of the four ERSD goals, a timeline of the expected research results over the next 15 years is shown in Table 1. Expected results are broken into three periods: near term, intermediate term and long term. However, it should be understood that progress in many of these areas will be continuous across these somewhat arbitrary divisions. These metrics are, in fact, the minimum that might be expected to be achieved by ERSD programs. It is anticipated that there will be numerous additional accomplishments and potential spin-offs to related fields, thus broadening the overall impact of ERSD supported research.

Table 1. Timeline of expected research results

Division Goal	Near-term priorities	Intermediate-term priorities	Long-term results priorities
1. Improved understanding of contaminant fate and transport	Numerical models that integrate geochemistry, hydrology and biology of contaminant fate and transport.	Biogeochemical understanding of the complex relationships between microbes and the environment Conceptual and numerical models for integrating across relevant scales of space and time New methods for assessing uncertainty	Large-scale, fully coupled reactive transport simulators Experimental verification of coupled fate and transport models through long-term field experiments
• **2. Scientific foundation for the development of characterization tools for assessing contamination and techniques for long term monitoring**	Geophysical techniques for locating contamination Field test new in situ imaging techniques new techniques for characterizing HLW in tanks	Non-invasive techniques to determine in situ transport characteristics [Characterization techniques for tank waste heels]	Sensors for monitoring the integrity of waste storage and the stability of immobilized wastes Cost-effective, remote long-term monitoring systems
3. In situ remediation of hazardous materials dispersed in the environment	Field test of bio-immobilization of radionuclides and toxic metals in the subsurface Phytoremediation approaches for DOE relevant contaminants.	Estimates of rates of remobilization of bio-contained toxic metals New materials for reactive and passive barriers Understanding of ecological impacts of remediation approaches under investigation	Predictive numerical models of long term in situ metal and radionuclide immobilization
4. Cost-effective and safe management and treatment of stored high level wastes	Prediction of HLW tank chemistry evolution New separations methods for waste volume reduction	[Designer materials for alternative waste forms]	[Methods for stabilizing underground storage tank "heels" for closure]

4. ERSD Field Research Centers

The research at the ERSD Field Research Center focuses on comprehensive, integrated, long-term field studies of topics with broad applicability to DOE. Research conducted at the Field Research Center (FRC) involves interdisciplinary teams of researchers who share results on a regular basis and are closely tied to experimental and modeling efforts. Only in this way can the issues of complexity and scaling be addressed. The existing and planned suite of ERSD Field Research Centers is a unique DOE contribution to the environmental community and is operated as a group of collaborative facilities.

Model predictions and laboratory-scale experimental results require confirmation under the actual conditions present in nature. In order to validate these findings, field scale studies must be performed for extended periods of times (years to decades). Field experiments are tremendously challenging because of the complexity of the environment, the difficulty of controlling key variables and our limited ability to measure key parameters. Nevertheless, field-scale experiments allow the identification of critical processes for predictive modeling. Small-scale experiments are limited in their ability to provide information about the impacts of large-scale geologic or hydrologic features on the fate and transport of contaminants. Field experiments provide the means for assessing interactions among physical, chemical, and biological processes occurring in the "fully coupled" environmental system, which is difficult, or impossible, to mimic in the laboratory.

The initial Field Research Center (FRC), located in the Bear Creek Valley of the Oak Ridge Reservation, is supported by the ERSD NABIR program. The FRC, which has been in operation for almost three years, currently supports three interdisciplinary, hypothesis-driven field studies and supplies environmental samples to over 30 researchers.

There is a need for additional long-term field research sites that encompass the range of environmental conditions and remediation problems relevant to DOE. Such multidisciplinary field research sites allow researchers to evaluate the impacts of natural variability and to understand processes that operate over ranges of spatial and temporal scales pertinent to environmental remediation. FRCs also provide valuable information on how natural attenuation affects the fate and transport of contaminants.

The FRCs encourage the integration of projects supported under the four ERSD programs as well as other DOE, federal, academic and commercial environmental organizations. Researchers supported within different programs work as interdisciplinary teams to address a specific research problem at a given site.

5. Program Integration and Contribution to Goals

The understanding and solution of complex environmental problems generally require multidisciplinary collaboration. For example, understanding the general problem of fate and transport of an environmental contaminant requires contributions from geologists, biologists, chemists, hydrologists, physicists, and meteorologists. Ersd will strive to provide research opportunities and facilities that foster interactions among experts with different backgrounds and expertise. The development of comprehensive descriptions of environmental processes and remediation approaches will be encouraged. By supporting major multidisciplinary endeavors, the ersd can provide a broad and sustaining foundation for a field that is often fragmented by traditional disciplinary boundaries. The Field Research Centers will play a central role in integration; as has been shown at the initial frc.

The four programs within ersd are, in many respects, complementary and mutually supportive. For example, while the nabir program focuses on the role of microbes on contaminant behavior, a large portion of the emsp programs focuses on the geochemical aspects of contaminant behavior. Since these geochemical effects are not separable from biological ones, the research will be strengthened significantly by studying them together. In addition, the needs in computational modeling for fate and transport, as well as for characterization are similar or identical for both programs. Characterization and monitoring tools are developed both in emsp and emsl. Emsl provides state of the art environmental analytical capabilities to researchers both within and outside of ersd. Additionally, the ecological expertise and resources of srel is actively integrated with other ersd research programs, particularly with the frcs.

By placing these four programs under the aegis of one Division, an opportunity is presented to promote interactions so that "the whole will be greater than the sum of the parts." In addition to integration through the frcs, the following steps will help to facilitate increased interactions among the programs:

- Cross-program collaborations and teaming will be encouraged among ersd investigators at frcs. Srel can provide critical data and insights regarding long-term ecological processes and impacts of doe activities as well as facilitating access to srs field sites. Such collaborations will be accomplished by joint solicitations for projects that bridge several ersd programs.
- "At-large" invitations will be provided to annual program Principal Investigator meetings. PI's from all programs will be invited to annual meetings and workshops, as appropriate.
- Research specialties can reach critical mass with support from more than one program. For example joint investments in development of new non-invasive geophysical tools or application of synchrotron radiation to radionuclide speciation or microbial protein structure would benefit multiple programs within ersd, as well as other programs in the Office of Science and elsewhere in doe.
- Researchers in nabir, emsp and srel are encouraged to take advantage of the unique and powerful instrumentation at emsl. Workshops are supported to familiarize

researchers with EMSL capabilities. Moreover, EMSL will develop "Grand Challenges" (e.g., in biogeochemistry) in which NABIR, EMSP and SREL researchers can participate.

6. ERSD Linkages

ERSD's interactions with other entities within the Office of Science, within the DOE, and throughout the federal government and environmental science community are essential to achieving its mission. Coordination and joint efforts allow program resources to be leveraged and extended.

6.1 Coordination within DOE

- *Office of Biological and Environmental Research (BER)*

BER is ERSD's home within the DOE Office of Science, so it naturally offers numerous opportunities for complementary efforts. BER programs are at the interface of the biological, physical, and computational sciences. The multidisciplinary nature and goals of ERSD continue in this BER tradition. Among the other BER Divisions and programs, several stand out as having close linkages to ERSD programs.

The *Genomics: GTL* program is seeking an understanding of "environmental genomics" as one of its major goals. In addition, it focuses to a large extent on microbial genomics. The importance of microbes in geochemical reactions is only now being recognized. Bacteria and microbes impact most geochemical process, including the weathering of rocks, the fate of contaminants, and the formation and disappearance of minerals. Likewise, the study of microbial genomics will be most meaningful when understood in the context of the natural environment. Thus, these two programs are not only linked, but are interdependent as well. It is expected that ties between ERSD and GTL will grow stronger as both programs develop.

The Joint Genome Institute (JGI) has been responsible for sequencing genomes of a number of microorganisms important to bioremediation. In the future, the development of systems for high throughput functional genomics at JGI will be important for studying microorganisms involved in bioremediation.

Research in Low Dose Radiation provides a new scientific basis for determining the health risks from low doses of ionizing radiation that could be important as risk is emphasized in cleanup efforts.

The Climate Change Research Division (CCRD) shares with ERSD an interest in multimedia transport issues. CCRD modelers involved in improving representation of air-land-ocean interactions face problems similar to those faced by modelers simulating reactive transport of various chemical species in subsurface media. Moreover, regional changes in precipitation patterns that result from global climate change have the potential to affect both the transport of contaminants by surface and near-surface hydrologic systems, as well as the availability of potable water, both of which are issues that are of interest to ERSD programs.

Within CCRD, the purpose of the Cascade of Scales initiative is to identify and understand mechanisms and pathways of response of complex ecosystems in the range of scales over which they operate (molecular to regional). The research at SREL complements this initiative, as that program seeks to understand long-term ecological trends and patterns as well as the impacts of DOE activities on those functions.

CCRD researchers will continue to use EMSL for computation and for instrument development, such as in the areas of aerosol detection and characterization of organic matter in soils.

ERSD and the Medical Sciences Division (MSD) share a strong interest in research into new imaging modalities.

- *Office of Basic Energy Sciences (BES)*

BES research programs in geosciences, heavy element chemistry and separations, engineering sciences, materials science and biosciences have already yielded results that the EMSP and NABIR programs have been able to build upon. BES also is responsible for the construction and operation of many of the large-scale experimental user facilities that have become essential tools for ERSD researchers. In particular, the availability of the BES-operated synchrotron X-ray light sources has greatly enhanced the ability to probe the chemical speciation of contaminants in the environment. Environmental science is now the fastest growing area of application for the light sources. ERSD will continue to work closely with existing BES programs and to seek opportunities for new linkages with emerging BES initiatives, such as the Nanoscale Science Research Centers and the Spallation Neutron Source, which currently are under construction.

- *Office of Advanced Scientific Computing Research (ASCR)*

The ERSD works closely with ASCR to ensure that the high-end computational resources within the EMSL are of the highest capability for BER relevant science, and that time allocations on the EMSL system do not duplicate allocations made at high-end computational facilities managed by ASCR. In addition, ERSD has been working with ASCR to develop the case that *reliable prediction of field scale subsurface behavior* will be the basis for decisions on environmental stewardship and the protection of human health with long-term implications for U.S. environmental and energy policy. As a result, subsurface modeling has been identified by ASCR as a critical area for advanced computing research.

- *DOE Mission Offices*

ERSD interfaces with the DOE field offices and contractors, the Office of Environmental Management and other DOE mission offices concerned with preventing, treating or controlling environmental contamination. ERSD will build on and expand the relationships that EMSP, NABIR, and SREL have established with the cleanup sites.

ERSD, together with BES, is a member of a DOE coordinating committee that deals with materials issues with all of the relevant mission areas. In addition, ERSD has been working with the Office of Civilian Radioactive Waste Management (OCRWM) in developing their science program for Yucca Mountain. A joint ERSD/OCRWM workshop on vadose zone contaminant transport is being planned.

Opportunities also are likely to arise for ERSD programs and facilities to support other DOE mission offices. For example, ERSD research has aspects that are relevant to the Office of Legacy Management. Research on waste processing and waste form performance are highly relevant to the DOE Office of Nuclear Energy, Science, and Technology's Advanced Fuel Cycle Initiative, which seeks to develop reprocessing and fuel treatment technologies that are cleaner, more efficient, less waste-intensive, and more resistant to proliferation.

6.2 Coordination with Other Federal Agencies and Non-governmental Organizations

ERSD objectives for interacting with other federal agencies and the larger environmental remediation community generally are twofold. First, through these interactions, ERSD can leverage limited resources by collaborating on common or complementary interests. Second, these interactions allow ERSD to coordinate and strengthen federal programs that address environmental remediation. ERSD's principal interactions are with the National Science Foundation (NSF), U.S. Environmental Protection Agency (EPA), and the Strategic Environmental Research & Development Program (SERDP). Coordination with other agencies also is facilitated through the National Science and Technology Council's (NSTC) Committee on Environment and Natural Resources (*e.g.,* the Toxics and Risks and the Water Quality and Availability Subcommittees), and the Committee on Science (*e.g.,* Interagency Working Group on Environmental Biotechnology).

Non-Governmental Organizations

The ERSD's connection with the National Academies is through study projects performed by National Research Council committees overseen by the Board on Radioactive Waste Management. This body has played a major and longstanding role in guiding EMSP. National Research Council bodies of interest to ERSD program areas include the Board on Chemical Sciences and Technology, Board on Earth Sciences and Resources, Water Science and Technology Board, and the newly formed Western Water Resources Coordinating Council.

Scientific professional societies represent an important nongovernmental source of information, resource networking, and advisory talent for ERSD programs. Societies with which the Office of Science has longstanding ties include the American Association for the Advancement of Science (AAAS), American Chemical Society (ACS), American Society for Microbiology (ASM), American Physical Society (APS), American Geophysical Union (AGU), and Materials Research Society.

7. Conclusion

The fundamental understanding developed in ERSD programs is and will be used by DOE sites in their decision making and technology development efforts for cleanup. However, this understanding has application beyond DOE site cleanup. It will help to provide solutions for environmental problems throughout the Nation and worldwide. Hazardous wastes in the environment from many sources threaten human health and the environment. While some of the fundamental science relevant to remediation of DOE sites may be unique to DOE (*e.g.*, geochemistry of high-level radioactive wastes), there are substantial commonalities with many environmental issues. For example, the basic processes that control the fate and transport of contaminants in the near-surface and subsurface environment are common to problems involving agricultural pollution, the fate of industrial effluents, the safety and quality of drinking-water supplies, acid mine drainage, and a host of other issues involving the aqueous transport of contaminants in surface waters and groundwater. Similarly, the societal context in which difficult and costly DOE remediation decisions must be made has many aspects in common with other decisions dealing with environmental hazards. ERSD will continue to contribute in significant ways to our understanding of life on Earth and how living organisms interact with and respond to natural and anthropogenic processes.

Research supported by ERSD provides the scientific basis for development of sound environmental policy. Thus, it is critical that ERSD results be communicated widely through workshops and conferences that bring together researchers, regulators, and technical staff from DOE sites. ERSD will continue an open and constructive dialogue with colleagues in the Office of Environmental Management and stakeholders at DOE sites. This dialogue will serve to establish common ground and help to identify research needed to inform environmental policy.

8. Contact Information

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