The Office of Groundwater & Soil Remediation Fiscal Year 2011 Research & Development Program - 11513

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ABSTRACT

The U.S. Department of Energy's (DOE) Office of Groundwater and Soil Remediation support technology development and technical assistance for the remediation of environments contaminated by legacy nuclear waste. The core of the program is centered on delivering proactive, responsive expertise and technologies with highly-leveraged, carefully selected investments that maximize impact on life-cycle cleanup costs and risks across the DOE complex. The program currently focuses on four main priorities: improved sampling and characterization strategies, advanced predictive capabilities, enhanced remediation methods, and improved long-term performance evaluation and monitoring.

In FY 2010, the program developed a detailed research and development (R&D) plan in support of a larger initiative to integrate R&D efforts across DOE's Office of Environmental Management. This paper provides an overview of the high priority action areas and the program's near-term technical direction.

INTRODUCTION

The U.S. Department of Energy (DOE) manages some of the largest groundwater and soil contamination problems and subsequent cleanup responsibilities in the world, in terms of the sheer volume of affected groundwater and soil, number of plumes, complexity of hydrogeologic settings, and diversity of contaminant types. DOE must remediate 40 million cubic meters of soil and sediment and 1.7 trillion gallons of contaminated groundwater in highly diverse environments that are contaminated with radionuclides, metals, and organics [1]. Current groundwater and soil remediation challenges that will continue to be addressed in the next decade include cost-effective characterization, remediation, and monitoring of contaminants in the vadose zone[1] and groundwater. Many subsurface vadose zone environments within the DOE complex consist of complex stratified layers of unconsolidated and water-unsaturated sediments that are in many places contaminated with radionuclides, metals, organics, and, in some cases, complex mixtures. This contamination originated from a number of sources, including intentional disposal to the ground surface through the use of cribs, retention basins, and trenches,

[1] Vadose zones are unsaturated regions of the subsurface environment above the water table. Contamination in the vadose zone and the underlying groundwater is affected by release from various sources, which include volitization, pond sediments, buried waste, storage basin sludge and wastes in underground storage tanks.

and from unintended tank waste releases. In many cases, minimal historical information exists regarding the magnitude, timing, and content of contaminant releases, thus necessitating estimation of the source terms. Many of the contaminated groundwater sites require additional characterization; most require final remediation decisions; and all will require long-term monitoring. Although DOE's Office of Environmental Management (EM) has made significant progress in its restoration efforts at sites such as Fernald and Rocky Flats, many of the remaining challenges are the most complex ever encountered by the subsurface science community, particularly at larger sites such as Savannah River, Hanford, and Oak Ridge.

Field research centers are being developed to enable transformational solutions and perform side by side testing of alternatives for the remediation at the DOE sites. These centers will allow the public, regulators and technology developers to assess the technologies under the same conditions. These centers will be located at Savannah River, Hanford, and Oak Ridge.

The smaller sites across the complex have issues similar to those of the large sites and some are significant. For example, at Paducah there is a mixed plume of ^{99}Tc and solvents deep in the aquifer. Due to the rate of movement of the groundwater and the depth to the contaminants this is a difficult area to remediate. The research efforts at the larger sites will be used to develop a specific solution for this problem. The next phase of that effort will be facilitating technology transfer.

GROUNDWATER & SOIL REMEDIATION RESEARCH AND DEVELOPMENT

The Groundwater and Soil Remediation (GW&S) Research and Development (R&D) program develops transformational technologies and methodologies to expedite subsurface remediation at DOE sites as part of the EM cleanup mission. The complexity of the groundwater and soil remediation effort requires a multi-faceted R&D program—consisting of multiple initiatives and field sites for applied research—in which each research initiative interconnects with others to enable development and implementation of holistic solutions based on scientific understanding of the subsurface environment. In the following figure, the initiatives are depicted as the core of the program and the Field Research Centers facilitate the demonstration of the new technologies and processes at a field scale.

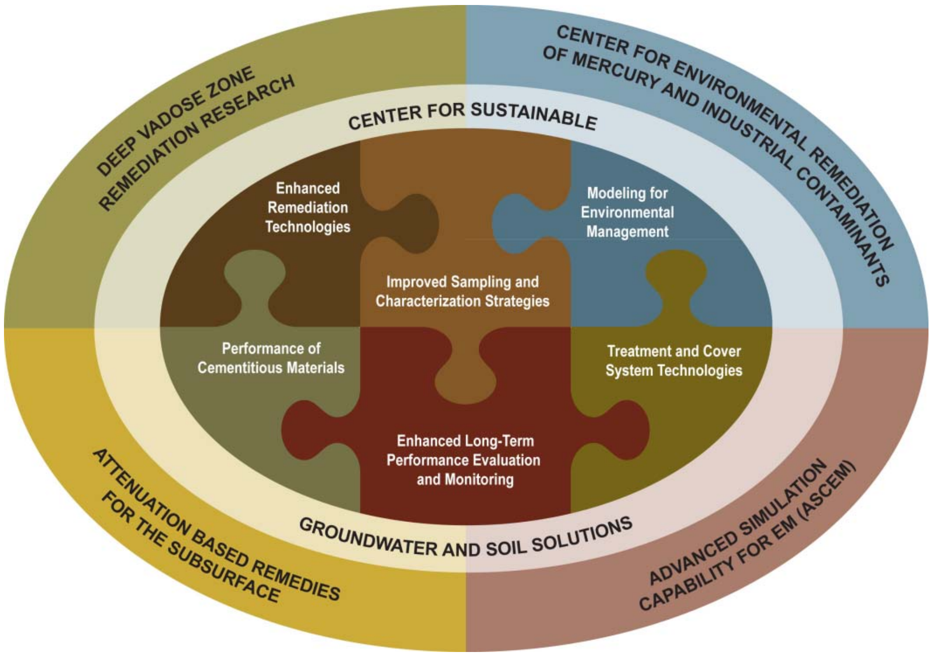

Fig. 1: Groundwater and Soil Remediation Research and Development Program Structure

The success of the GW&S R&D program requires multi-institutional and multi-disciplinary research teams composed of scientific specialists and from multiple agencies, including national laboratories, universities, industry, and other federal and state agencies. Much of the work associated with the GW&S R&D program elements is conducted as an integrated effort within the three applied field research centers and Advanced Simulation Capability for Environmental Management (ASCEM) shown on the outside of the figure:

- Attenuation-Based Remedies for the Subsurface - Applied Research Center at Savannah River
- Deep Vadose Zone Remediation Research - Applied Field Research Center at the Hanford Site
- Center for Environmental Remediation of Mercury and Industrial Contaminates at Oak Ridge

Attenuation-Based Remedies for the Subsurface - Applied Research Center at Savannah River

Attenuation of metals and radionuclides is integral to achieving remedial objectives for contaminated groundwater. Metals and long-lived radionuclides, those posing the greatest risk to the environment, are not typically destroyed requiring either in-place treatment or removal followed by treatment. Pump and treat approaches employing ex situ (above ground) treatment methods are not economically feasible and in many instances will create additional waste streams requiring further treatment. For in-place treatments to be successful the contaminants must be stabilized or detoxified for periods of time that are on the order of hundreds to thousands to years. An inherent truth is that once the source of contamination is removed in time all waste sites will evolve to their natural condition. Thus the metal and radionuclide contaminants must be rendered stable or non-toxic in that setting. Success is predicated on understanding the attenuation mechanisms and their effects on contaminant mobility. Technical issues associated with this understanding are: addressing heterogeneity in hydrogeological and geochemical properties within aquifers; understanding how small scale field and laboratory measurements relate to field scale processes; and accounting for adsorption of contaminants. All of these issues have been the subject of extensive basic scientific research, but this research has not crystallized into application-based approaches that are readily employed at many waste sites or are tractable for the average waste site owners.

The Attenuation-Based Remedies for the Subsurface - Applied Research Center at Savannah River will integrate the end-users experience with site history, operational constraints, and budgetary issues; the Office of Science's wealth of basic science knowledge; and regulator expectations to ensure consistency with regulatory policy and guidance in order to develop an applied science solution resulting in "tools" that are transferable to the DOE complex. EM will transition scientific results with advanced simulation tools into applied solutions that will be developed through the framework of the field research centers. The framework facilitates integration of resources and creativity to provide sites with practical tools and strategies for characterization, remediation, and monitoring of attenuation-based approaches for metal and radionuclide contamination in the vadose zone and groundwater. The Attenuation-Based Remedies for the Subsurface - Applied Research Center will provide the modeling for environmental management program element information on site specific hydrogeology and biogeochemistry, defining contaminant source and plume characteristics and controlling processes, and remedial strategies which include remedial and monitoring technology implementation and performance metrics.

During FY 2011 multiple applied science research efforts will be initiated that focus on addressing three main research areas that capture the nine technical targets identified as central to this applied research center's program. The three main research areas for the Attenuation-Based Remedies for the Subsurface - Applied Research Center are: development of enhanced attenuation technologies; development of tools and approaches to support field characterization and monitoring; and development of tools and approaches to support decision-making. The research will include both laboratory-bench scale development as well as field-based studies and will be performed by researchers representing academia, industry and the national laboratories. Testing of geophysical tools by the DOE Office of Science (SC) Sustainable Systems Scientific Focus Area will support their continuing research efforts that support both the second and third research areas identified above. In addition, work will continue with the Interstate Technology and Regulatory Council (ITRC) to educate regulators, industry, and stakeholders on approaches and tools to address the technical challenges associated with metal and radionuclide contamination in groundwater.

Deep Vadose Zone Remediation Research - Applied Field Research Center at the Hanford Site

Inorganic and radionuclide contamination in the deep vadose zone is isolated from the surface environment, such that direct contact is not a factor in its risk to human health and the environment. Rather, the deep vadose zone serves as both a present and potential future source of groundwater contamination. Movement of contamination from the deep vadose zone to the groundwater creates the potential for exposure and risk to receptors through contaminant uptake from water withdrawn from wells or discharge to surface water resources. Thus, remediation solutions for the deep vadose zone target protection of the groundwater, specifically by preventing contaminants from exceeding established concentration limits once in the groundwater. The magnitude of the contaminant discharge (mass per time) from the vadose zone to the groundwater must be maintained low enough to meet the groundwater concentration goals by natural attenuation (e.g., adsorption processes or radioactive decay) or through remedial actions (e.g., contaminant mass or mobility reduction).

The deep vadose zone poses unique problems for characterization, monitoring, and remediation. The heterogeneous nature of the deep vadose zone makes detailed characterization of the distribution and extent of contamination very difficult; thorough characterization using traditional sampling and analysis is not cost-effective. Functionally, the methods for addressing subsurface contamination must remove contamination and/or reduce transport of contaminants through the vadose zone. However, because pore spaces are unsaturated, conventional remediation technologies such as pump-and-treat are ineffective. In addition, much of the contamination is too deep for conventional surface excavation and below the depth at which a surface infiltration barrier would sufficiently retard contaminant migration and protect groundwater. These issues and others combine to make the deep vadose zone one of the most challenging environmental remediation problems in the DOE complex today. Development of *in situ* remediation technologies or defensible technical data and justification for relying on natural attenuation may be the only way to remediate contamination in the deep vadose zone. Minimizing the flux of contaminants from the vadose zone to the groundwater with *in situ* techniques may be the only viable path to long-term stewardship of sites contaminated with metals and long-lived radionuclides other than physical removal techniques, which are costly and often simply move the problem from one location to another.

In recognition of the need to find a broader set of effective methods for characterizing, remediating and monitoring the deep vadose zone, DOE has prepared a long-range plan that identifies scientific and technological needs and opportunities related to the deep vadose zone at Hanford [2]. This planning effort focused on developing a set of basic and applied science gaps and opportunities that will be used to guide the integrated, collaborative Deep Vadose Zone Applied Field Research Center (DVZ-AFRC). The overall vision for DVZ-AFRC is to provide a technical basis to quantify, predict, and monitor natural and post-remediation contaminant discharge from the vadose zone to the groundwater and to facilitate developing *in situ* solutions that limit this discharge to acceptable levels and protect water resources.

Investments from DOE SC are being applied to understanding these processes and their relation to the biogeochemical and hydrologic conditions in the vadose zone. Site contractor resources are being applied to characterize the nature and extent of contaminants in the vadose zone, conduct treatability tests to quantify how technologies change the site and contaminant conditions, and to evaluate remediation options. One part of the DVZ-AFRC applied research effort integrates with these other efforts by providing laboratory- through field-scale data with a focus on relating vadose-zone process descriptions, contaminant nature and extent, and processes for treating the contaminant(s) discharge. These activities support development of site conceptual models and evaluating the long-term performance of remedies and are also related to ASCEM program efforts. ASCEM will aid EM in transitioning scientific results into applied solutions that will be developed through the necessary framework of the DVZ-AFRC, which facilitates integration of resources and creativity to provide sites with viable alternative remedial strategies to current baseline approaches for persistent deep vadose zone contamination. The DVZ-AFRC will provide ASCEM information on site-specific hydrogeology and biogeochemistry defining contaminant source characteristics and controlling processes, and remedial strategies including remedial and monitoring technology implementation and performance metrics. ASCEM will use this information to assess the performance of remedial strategies and, through integration with the DVZ-AFRC, facilitate development of the scientific foundation, applied technologies, and remedial strategies necessary to make sound and defensible remedial decisions that will successfully meet the target cleanup goals in a manner that is acceptable to regulators. The DVZ-AFRC program also includes technology development efforts to enable application of innovative remediation techniques and improved amendment delivery processes for the deep vadose zone, to enhance remedy performance monitoring through application of geophysical techniques, and to develop flux-based monitoring for the vadose zone.

The technical objectives of the DVZ-AFRC effort are focused on four research and development categories. Within each of these categories, critical research and development lines of inquiry and opportunities are being identified and collaborative relationships with subsurface characterization and remediation activities at Hanford are being established. The four research and development categories are:

- **Remedial Design -** Perform fundamental and applied research supporting the design of surface and subsurface techniques to access and remediate DVZ contamination.
- **Controlling Processes -** Quantifying coupled hydrologic, geochemical, and microbial processes functioning in the DVZ is key to developing reliable conceptual models of moisture flux, contaminant movement, and remediation process efficacy in deep vadose zone environments.
- **Monitoring –** Develop and deploy efficient and effective monitoring methods for assessing the performance of remedies and for determining any long-term threat of contaminants reaching groundwater. Advance subsurface monitoring technologies including novel sensors, detectors, and data transmission techniques.
- **Predictive Modeling & Data Integration -** Simulate the integrated processes controlling moisture flux, contaminant transport, and remediation performance

The risk posed by deep vadose contamination creates an enormous environmental liability. DOE is committed to bringing forward the best capabilities possible to address the deep vadose zone at the Hanford Site and across the DOE complex. The impact of the DVZ-AFRC investments is to develop effective and economical solutions at Hanford and other DOE sites, while building upon available knowledge and capabilities, to meet cleanup goals. This approach will leverage investments from different DOE organizations, including sites across the DOE complex, working in basic science, applied research, and site engineering activities. DOE will use expertise from agency-wide activities, national laboratories, academia, and industry to work in collaboration with the Tri-Party Agreement signatories, site contractors, the public, and others to provide viable remedial technologies and strategies targeting baseline needs.

This approach will rely upon multi-project teams focusing on coordinated subsurface projects across the Hanford Site, and will facilitate research investments through the DVZ- AFRC as well as scientific studies from other DOE sites. The knowledge gained by the DVZ-AFRC will be used to transform science innovation into practical applications deployed by site contractors at Hanford and across the DOE complex. Carefully selecting investments will yield useful results within time frames supporting regulatory milestones (e.g., those in the Tri-Party Agreement), support development of documentation, and strengthen cleanup decisions. Investments will support both time-critical decisions and long-term, non-time-critical objectives. Balancing these competing drivers will sustain both "bias for action" and "scientific sufficiency" priorities for program implementation. This will support development of sustainable solutions that are broadly applicable throughout similar environments within the DOE complex (e.g., Los Alamos, Idaho, and Nevada sites).

During FY 2011, treatability tests will continue to evaluate potential approaches to remediate deep vadose zone contamination, and more closely integrated working relationships between user-inspired research and field-applied engineering will be established. In addition, a multiyear implementation plan is being developed to focus resource allocation on the most critical needs and opportunities.

Center for Environmental Remediation of Mercury and Industrial Contaminates at Oak Ridge

Historic uses of mercury at the Oak Ridge Reservation (ORR) in Oak Ridge, TN have resulted in contamination at the Y-12 National Security Complex (NSC) and Oak Ridge National Laboratory (ORNL). The ecosystem of EFPC in Oak Ridge remains contaminated with mercury, despite remedial actions at Y-12 that have reduced mercury inputs into EFPC by more than 90% since early 1980s. The current estimated mercury cleanup cost at the Y-12 NSC alone is $1 billion, base on the treatment and storage of a large estimated volume of mercury contaminated soil. Currently, the spatial subsurface distribution, speciation, and extent of mercury contamination in soils, sediments, and water at the Y-12 NSC site is poorly understood, thus poses high risk to mercury remediation efforts. In addition to mercury contamination at the Y-12 NSC, ORR has numerous other intractable environmental problems with industrial (such as U, Tc, Sr, Cs, and other radionulcides, metals, nitrate, PCBs, VOCs and DNAPL) migrating from a complex subsurface system composed of fracture rock and karst present beneath former burial grounds and disposal cribs. Given the diversity and complexity of onsite subsurface contaminants, an understanding of the various contaminant movement pathways and potential application of innovative remediation technologies and approaches will be critical to developing effective remediation decision-making.

The AFRC at Oak Ridge—Center for Environmental Remediation of Mercury and Industrial Contaminates—is tasked with developing cost-effective technical solutions for:

- Waterborne mercury remediation,
- Soil treatment, source zone identification, mercury characterization, and
- Conceptual and numerical modeling of contaminant fate and transport.

Waterborne mercury is addressed through the development and demonstration of innovative methods that utilize specialized resins, unique nanomaterials, or chemical treatment to transform, sorb, and/or remove mercury. Soil treatment targets in situ and ex situ approaches for removing mercury or stabilizing it within environmental matrices. Source zone identification and characterization efforts are focused on developing and deploying innovative tools and sampling approaches that can be used for in situ, real-time identification of mercury concentrations and speciation in soil gas, soil, and water. Characterization also includes developing an improved understanding of the relationship between the subsurface hydrogeology, observed mercury fluxes in water, and the mercury source zones. Finally, refinements to the existing conceptual modeling are being used to identify the locations with the highest risk and uncertainty based upon existing knowledge. The activities being conducted as part of the AFRC at Oak Ridge are also leveraging investments from DOE SC Science Focus Area at ORNL focused on understanding the mechanisms and processes that control mercury methylation. In addition to the mercury remediation activities described above, a portion of EMs investments in the AFRC at Oak Ridge will used to provide assistance to the ORR in the development of a holistic strategy for various milestones listed in the Federal Facilities Agreement (FFA). Additionally, the AFRC at Oak Ridge will be providing input data to ASCEM advance simulation tool—such as, site specific hydrology, geology, mineralogy, microbial, and chemical compositions and reactions—to improve existing predictions on the fate and transport of mercury and other contaminants. ASCEM will provide a useful tool that can be leveraged to design more effective remedial strategies and approaches, in order to achieve the required performance metrics.

In FY 2011 the center activities consist of assessing alternative water treatment technologies that can treat mercury at or near the source zones where the Hg concentration is high and the volumetric flow is relatively low. A select number of the sorbents that were evaluated in FY 2010, will be used in FY 2011 using site specific water to examine the kinetics and capacities for Hg uptake. Source zone characterization will focus on improving the existing information on the mercury distribution and speciation around several key facilities. Additionally the center plans to work with Oak Ridge Operations, site contractors (B&W Y-12 and BJC) to initiate a strategy that will define a path forward on how to address the remaining high risk issues currently facing the ORR. Although this only provides a brief synopsis of the key FY 2011 activities, the AFRC at Oak Ridge is positioned to significantly impact the existing need for ORR to move EFPC closer to achieving compliance with its designated uses under the FFA and Clean Water Act: recreation and the propagation of fish and wildlife.

Advanced Simulation Capability of Environmental Management

ASCEM consists of an initiative to develop a state-of-the-art scientific tool and transformational approach for integrating data and scientific understanding into a framework for remediation decisions. By combining today's petaflop supercomputing capabilities, new and open source high performance computing applications, data analysis and integration approaches, and increased understanding of subsurface hydrological-biogeochemical processes, ASCEM will advance the approach for subsurface contaminant fate and transport simulations to support risk-informed environmental remediation and waste management decisions. It is based on new insights and approaches being developed through the DOE Office of Science and other research agencies and will be updated as further advances occur.

ASCEM is organized into three thrust areas: (1) Multi-Process High Performance Computing (HPC), (2) Platform and Integrated Toolsets, a user interface with associated toolsets, and (3) Site Applications. The relationship between the thrust areas is illustrated in the Figure below. The HPC Thrust includes meshing approaches, new solvers for multi-physics coupled processes, advanced methods of discretization in time and space, capabilities to select and coordinate the use of problem-specific processes, and application-programming interfaces. The Platform Thrust includes tools to facilitate model setup and analysis, parameter estimation and uncertainty quantification, risk assessment and decision support, information and data management, and visualization in a consistent and flexible user interface and modeling workflow. The Site Application Thrust coordinates and implements site demonstrations through ‘working groups’ to ensure that the ASCEM is developed in a manner that will engage users and benefit DOE Environmental Management’s remediation obligations.

The first year of the ASCEM project included completion of several deliverables, including: a survey of end-users to identify practical needs, technical requirements for the Platform and HPC toolsets, quality assurance framework, and Phase 1 of the site demonstrations. The first (Phase I) demonstration, largely undertaken from September through December, 2010, focused on illustrating individual (stand-alone) ASCEM capabilities developed during the first year.

The Data Management component adapted and implemented open-source, web-based tools to allow users to easily import, browse, filter, graph, query, and output datasets common to environmental remediation investigations. Capabilities were developed to allow visualization of these and other datasets, including depositional information, hydrostratigraphic surfaces, and the evolution of contaminant plumes. ASCEM capabilities were also developed to allow a user to perform uncertainty quantification using a variety of different analysis approaches within a graphical user interface (GUI). Prototypes of selected toolsets within the ASCEM Multi-Process HPC simulator, called Amanzi, were also developed and tested on laptops and desktops running both Linux and Mac OS X, and on several supercomputers including the Cray XT4 system at NERSC using 256 cores and the Hopper XE6 at NERSC using 2304 cores. Both unstructured and structured mesh approaches were used to simulate geochemical and hydrological processes using F-Area data and information.

Two supplementary efforts were also undertaken to advance new ASCEM capabilities and engage different end user communities. These advances include use of an adaptive mesh refinement approach to more efficiently and accurately simulate potential release from the degradation of closed tanks, and development of approaches to quickly visualize simulation and UQ output. An ASCEM model setup tool was developed in conjunction with data from the Hanford vadose zone to translate and visualize conceptual model information into numerical model input within the same computing environment.

In 2011 the ASCEM team is primarily focused on integrating the components developed in 2010 into a homogeneous, easy to use simulation package and developing additional capabilities of the codes. It is expected that the first user release of the ASCEM code will be available in 2012.

MEETING THE CHALLENGE – PROGRAM TECHNICAL UNDERPINNINGS

DOE EM's *Engineering and Technology Roadmap* [3], the National Research Council's *Advice on the Department of Energy's Cleanup Technology Roadmap, Gaps and Bridges* [4], and input from field organizations compose the basis for the GW&S R&D program.

To meet those challenges the GW&S R&D program features the six main areas that are being developed at the field research centers:

1. Enhanced Remediation Technologies
2. Modeling for Environmental Management
3. Treatment and Cover System Technologies
4. Enhanced Long-Term Performance Evaluation and Monitoring
5. Performance of Cementitious Materials
6. Improved Sampling and Characterization Strategies.

The near-term focus is primarily upon enhancement of remediation technologies and development of a high performance modeling and simulation tool. The Enhanced Remediation Technologies area provides for development and field demonstration of technologies and processes that will eliminate costly active remediation of dispersed contamination in groundwater and soil, such as pump-and-treat. The Modeling for Environmental Management area will provide the platform to transfer fundamental science to the applied GW&S R&D program and to theoretically investigate and optimize remedial actions. The next three main areas identified above are in the planning and development phases but represent critical future technology development and deployment initiatives in terms of long-term closure performance and the efficient transfer of waste units to more cost-effective passive end states. An additional initiative area identified in the *Roadmap* [3] is Improved Sampling and Characterization Strategies. In the current GW&S R&D program this sampling and characterization initiative is applicable to all areas. Work on this cross-cutting initiative emphasizes the development, demonstration and deployment of cost-effective technologies that accurately characterize subsurface plumes and provide sound technical bases for selecting, designing and deploying remedies. Gaining federal and state regulatory acceptance of next-generation sampling and characterization technologies and approaches and leveraging national basic and applied science programs and past investments are part of this initiative.

The Enhanced Remediation Technologies R&D program area includes four primary initiatives to enable transition from active to more passive subsurface remediation. These include:

- The *Attenuation-Based Remedies for Metals and Radionuclides in the Groundwater* initiative develops technical guidance, tools, and new approaches that will foster consideration of attenuation-based remedies,[2] where appropriate, at sites with metal or

[2] Attenuation-based remedies for contamination in groundwater reduce or eliminate migration of contaminants using naturally-occurring processes to provide a sustainable remediation of the problem. Naturally-occurring or enhanced remedies are the only paths to long-term stewardship of sites contaminated with metals and long-lived radionuclides other than very costly physical removal by pump-and-treat methods or excavation, which is impractical in cases of deep vadose zone contamination.

radionuclide-contaminated groundwater. This initiative will be part of the Attenuation-Based Remedies for the Subsurface - Applied Research Center at Savannah River.

- The *Advanced Remediation Methods for Metals and Radionuclides in the Vadose Zone* initiative generates scientific data, assessment tools and cost-effective in situ remediation technologies to meet remedial objectives at sites with metal or radionuclide-contaminated vadose zones. This initiative will be part of the Deep Vadose Zone - Applied Field Research Center at the Hanford Site.

- The *Attenuation-Based Remedies for Chlorinated Solvents in Groundwater and Vadose Zone* initiative identified a three-prong approach to moving forward with the implementation of attenuation-based remedies for treating chlorinated solvents. The approach includes: (1) develop and promote approaches and tools that will support the generation of technically defensible information to transition from source/active treatments to attenuation-based approaches (Enhanced Attenuation and Monitored Natural Attenuation); (2) investigate the ability of attenuation mechanisms to facilitate natural attenuation in settings representative of many DOE plumes and develop tools that will facilitate the evaluation and monitoring of attenuation mechanisms that are promising; and (3) develop and conduct training seminars independently and in conjunction with ITRC.

- The *Mercury Characterization and Remediation* initiative develops cost-effective treatment technologies and is closely associated with the tasks discussed in the section above for the Center for Environmental Remediation of Mercury and Industrial Contaminates at Oak Ridge.

IMPACT OF THE GROUNDWATER & SOIL REMEDIATION RESEARCH AND DEVELOPMENT PROGRAM

Near term, our understanding of subsurface heterogeneity and complexity will be maximized using state-of-the-art scientific knowledge of subsurface physical, chemical, and biological processes and controls. This new knowledge will minimize sampling and analysis costs and improve implementation and performance of remedial strategies. In the long-term, the program will realize a consistent approach to decisionmaking and broad implementation of remedial strategies across the DOE complex, this investment will provide a life-cycle cost savings of as much as two-orders of magnitude compared to the initial research costs by implementing approaches that rely upon natural processes to support implementation of sustainable long-term solutions.

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