

**Fiscal Year 2010 Program of the U.S. DOE Office of Groundwater and Soil Remediation - 10587**

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**ABSTRACT**

The U.S. Department of Energy's (DOE) Office of Groundwater and Soil Remediation supports technology development and technical assistance for the remediation of environments contaminated by legacy nuclear waste. It is a proactive, responsive program whose investments are highly leveraged and carefully selected for maximum impact on life-cycle cleanup costs and risk 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. Contaminants of interest include long-lived radionuclides, mercury and other metals, and chlorinated solvents. The behavior of these contaminants and the complexity of environments in which they reside are studied within five specific program action areas. This paper provides an overview of the action areas and the program's near-term technical direction and budget.

**INTRODUCTION**

The mission of the U.S. Department of Energy's (DOE) Office of Groundwater and Soil Remediation is to support the development of technology and scientific expertise necessary for the safe, effective cleanup of environments impacted by nuclear weapons development and nuclear energy research. Groundwater and Soil Remediation invests in solutions to DOE's most intractable, high-risk environmental problems. It employs a proactive, responsive approach that includes extensive collaboration and resource leveraging with partners in industry, academia, government, national laboratories, and DOE field sites. Shared knowledge boosts the impact of DOE's investments to yield significant reductions in remediation life-cycle cost and risk across the DOE complex.

Groundwater and Soil Remediation is engaged in multiple aspects of remediation technology development and support. It contributes technical assistance to its sites and partners by reviewing DOE soil and groundwater remedies; coordinating technical teams to address site-specific groundwater and soil remediation problems; providing support for performance assessments; and supporting risk-based cleanup standards. It initiates and sustains technology development through targeted funding of applied research programs at national laboratories, universities, and supporting institutions such as the Savannah River Ecology Laboratory. It achieves leveraging and collaboration by monitoring Congressionally-directed activities in groundwater and soil programs and by working closely with the Interstate Technology and Regulatory Council (ITRC), the DOE Office of Science, and the Department of Defense's Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP). These efforts ensure the successful

translation of basic science discoveries into applied environmental solutions. The Office of Groundwater and Soil Remediation also facilitates complementary, multi-agency approaches to solve technical challenges and to avoid unnecessary duplication of investments and effort. This paper describes the near-term priorities and activities of its program.

## **GROUNDWATER AND SOIL REMEDIATION PRIORITIES AND NATIONAL ACADEMY OF SCIENCE RECOMMENDATIONS**

Groundwater and Soil Remediation priorities address DOE site cleanup needs and the technical breakthroughs needed to achieve regulatory milestones. Current priorities include improved sampling and characterization strategies, advanced predictive capabilities, enhanced remediation methods, and improved long-term performance evaluation and monitoring. These areas are emphasized based on input from DOE field offices, the National Academy of Science (NAS) and other external organizations, the environmental remediation community of practice, and the DOE Office of Environmental Management (EM), which is the parent organization of Groundwater and Soil Remediation.

EM is guided at its highest level by the 2008 *EM Engineering and Technology Roadmap* (“Roadmap”) [1], developed in response to a FY 2007 directive by the Energy and Water Development Appropriations Committee of the U.S. House of Representatives. This document identifies strategies for addressing technology gaps, risks, and uncertainties in DOE’s environmental management program. Significant contributions to the Roadmap were made by NAS, and at EM’s request, NAS recently reviewed the Roadmap. Its recommendations were published in 2009 as *Advice on the Department of Energy’s Cleanup Technology Roadmap* [2]. The report identified four technical gaps, defined as “shortfall[s] in available knowledge or technology that could prevent EM from accomplishing a cleanup task on its expected schedule and/or budget” [2]. The gaps, listed in Table I, focus on insufficient understanding of contaminant behavior, the potential unsuitability of baseline remediation technologies, and poor understanding and inadequate demonstration of the long-term performance of waste containment materials and systems. Although the gaps highlight uncertainties and deficiencies in the understanding of natural and engineered environments, they also justify and reinforce the programmatic priorities of Groundwater and Soil Remediation. The program is integrating the NAS recommendations into its major action areas, as discussed in the following section.

Table I. Technical Gaps in Groundwater and Soil Remediation Understanding as Identified by the National Academy of Science [2].

Gap 1	The behavior of contaminants in the subsurface is poorly understood.
Gap 2	Site and contaminant source characteristics may limit the usefulness of EM’s baseline subsurface remediation technologies.
Gap 3	The long-term performance of trench caps, liners, and reactive barriers cannot be assessed with current knowledge.
Gap 4	The long-term ability of cementitious materials to isolate wastes is not demonstrated.

NAS Gap 1 refers to the complexity of contaminant behavior in heterogeneous environments of variable waste composition, hydrology, mineralogy, and microbiology under natural and engineered conditions. Biogeochemical processes are often dynamic and affect contaminant solubility, reactivity, sorption, transport, and other characteristics in ways that are difficult to predict with current knowledge. Unanticipated contaminant migration via preferential pathways

can result in expanded contaminated zones, missed regulatory milestones, delayed remediation progress, and significantly underestimated risks and costs. NAS noted that research and development by programs within DOE, the Environmental Protection Agency (EPA), the U.S. Nuclear Regulatory Commission, the U.S. Geological Survey, and other organizations have contributed to improved understanding of contaminant fate and transport. NAS recommended that EM continue its pursuit of enhanced characterization and monitoring methods for contaminant source and plume zones, with an emphasis on real-time, automated data collection. It also encouraged improvements to conceptual and numerical models of contaminant behavior. Finally, it suggested the development of technical criteria for delaying remediation when implementation is not scientifically sound.

Gap 2 focuses primarily on the limitations of the pump-and-treat method for groundwater remediation. Although this technology is mature, commonly used, and often able to prevent groundwater plume migration, it cannot always effectively and uniformly remove substantial quantities of contaminants. This is particularly true of environments with geologic strata of varying permeability. NAS cited examples of pump-and-treat systems at the Oak Ridge Reservation (Oak Ridge, TN) and the Hanford Site (Richland, WA) that have prevented expansion of carbon tetrachloride plumes but have not substantially impacted plume longevity or source zone mass. NAS recommended research to facilitate greater justification and use of monitored natural attenuation (MNA) and enhanced remediation methods such as bioremediation and permeable reactive barriers (PRBs).

Permeable reactive barriers and other engineered containment systems are the subject of Gap 3. NAS highlighted the lack of long-term (i.e., greater than 100 years) field data on the performance of structures designed to mitigate the spread of subsurface contamination. DOE performance assessments assume containment over long time frames, but current knowledge is insufficient for confident predictions of structural integrity or the uniformity and reactivity of PRBs even beyond several decades. Recommendations included research and development for improved monitoring systems to reduce uncertainty and facilitate timely system repairs; improved models that consider uncertainty and the temporal and spatial dynamics of containment systems; development of alternative remediation approaches that function effectively even as waste site geochemistry and hydrology evolves; and the use of containment structures as temporary or replaceable elements of a remediation strategy.

Gap 4 focuses on the difficulty of performance prediction for containment materials. Cementitious materials are widely used for waste encapsulation and tank grouting. However, the short-term behavior of metals and radionuclides in waste-form grouts cannot be extrapolated to long-term behavior. Both physical and chemical changes occur in cementitious materials over time, but the causes, rates, and extent of these changes are poorly understood. NAS cited the need for field data to support improved performance assessment models for grouts and other materials.

## **GROUNDWATER AND SOIL REMEDIATION ACTION AREAS**

The Office of Groundwater and Soil Remediation supports research, technology development, and technology demonstration in five action areas that correlate to its programmatic priorities

and the NAS recommendations described above. The action areas include advanced simulation and predictive capabilities; remedies for metals, radionuclides, and chlorinated solvents in groundwater and the deep vadose zone; and mercury characterization. They are discussed individually below.

The first action area, **Advanced Simulation Capability for Environmental Management (ASCEM)**, is a new initiative in Groundwater and Soil Remediation. It is planned to be a state-of-the-art scientific tool and approach for understanding and predicting contaminant fate and transport in natural and engineered systems. ASCEM evolved from the need for computational models that comprehensively represent site hydrogeology and contaminant geochemistry. It will develop scientific bases to support remediation activities and also provide robust models of subsurface and containment system behavior that can incorporate appropriate uncertainty and account for natural and anthropogenic changes. Furthermore, it will support the identification and collection of characterization data needed for the other four action areas. ASCEM is designed to address the critical need to reduce uncertainties and risks associated with DOE's environmental cleanup and closure program.

ASCEM will employ a modular, open-source, high-performance computing platform that permits integrated approaches to modeling and site characterization. This approach will be flexible enough to incorporate new knowledge and technical advancements as they become available. Users will not require expertise with high performance computing tools and interfaces, and they will be able to access the tool on platforms ranging from desktop computers to the high performance computing facilities available within DOE.

ASCEM leverages and builds upon the latest subsurface science research and computing technologies from multiple programs. These include the DOE Office of Science's Energy Frontier Research Centers (EFRC) and Scientific Discovery through Advanced Computing (SciDAC) program; EPA's Interagency Steering Committee on Multimedia Environmental Modeling (ISCMEM); the Russian Academy of Sciences; and the ITRC. ASCEM's core collaborators form a multidisciplinary team of geoscientists, materials scientists, and computational scientists from leading national laboratories, including Los Alamos National Laboratory, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, Oak Ridge National Laboratory, and Savannah River National Laboratory.

ASCEM has proposed aggressive goals to achieve acceptance by EM site users and regulatory oversight agencies. During the projected five-year development period, the project will establish requirements and design specifications, complete software prototyping, and demonstrate model capabilities in comprehensive test cases at selected DOE sites. Current planning also includes distributing a final toolset, providing support infrastructure, and conducting training sessions across the EM community. The integrated general-purpose model is ultimately anticipated to be widely used for many subsurface applications, such as high-level radioactive waste disposal and geologic carbon sequestration.

The second action area, **Attenuation-based Remedies for Metals and Radionuclides in Groundwater**, examines the reduction or elimination of metal and radionuclide migration using naturally-occurring or enhanced processes. Projects within this action area seek practical,

sustainable, and potentially more economical alternatives to baseline remediation methods for long-term site stewardship. Baseline methods include costly physical removal by pump-and-treat or excavation, which are impractical in contaminated zones of low permeability or in very deep environments, respectively. The action area will result in technical guidance, training, tools, and new approaches to foster consideration of attenuation-based remedies at sites with metal- and radionuclide-contaminated groundwater.

Research within this action area is being conducted at the Applied Field Research Site at the Savannah River Site in Aiken, SC. Baseline characterization has been performed to provide data for mass balance calculations for a contaminant plume, a key aspect of the project. Additionally, biogeochemical gradients and waste site evolution are being pursued as components of an organizing framework that site owners, regulators, and technical personnel can use to approach attenuation-based remedies. Biogeochemical gradients are defined as zones of variable biogeochemical conditions that control contaminant toxicity and mobility in the subsurface. Waste site evolution refers to the spatial and temporal dynamics of site biogeochemistry and hydrology under natural or anthropogenic pressures. For example, waste site characteristics change during contamination events, during active remediation, and during the slow process of returning to a “natural” state (which may or may not resemble the pre-contamination state).

The third action area is **Advanced Remediation Methods for Metals and Radionuclides in the Vadose Zone**. Contaminated vadose zone environments are potential sources of groundwater contamination, and the vadose zone also acts as a conduit for transport of metals and radionuclides (e.g., <sup>99</sup>Tc, <sup>90</sup>Sr, U, Pu, and Cr) from the ground surface. The natural capacity of the vadose zone for contaminant attenuation is often exceeded in arid environments that have historically served as waste disposal areas. Monitored natural attenuation may not be appropriate for contaminant source control under such circumstances. In situ enhanced attenuation methods have been proposed as alternatives to conventional methods for meeting remedial objectives, minimizing direct exposure to contamination, and limiting contaminant flux to groundwater. However, the justification and regulatory acceptance of new enhanced attenuation methods requires defensible technical data. The third action area will not only develop innovative remediation methods, but also provide the requisite performance data and assessment tools.

The vadose zone initiative is a collaborative effort by participants from Pacific Northwest National Laboratory (PNNL), the Department of Energy’s Richland Operations Office, PNNL’s Laboratory Directed Research and Development program, the DOE Office of Science’s Science Focus Area (SFA) program, and the Plateau Remediation Contractor (CH2M Hill) for the Hanford Site’s BC Cribs area. The project will develop a sound technical basis for selecting active remediation strategies based on geochemical and physical site conditions. One strategy under investigation is reagent delivery to deep vadose zone environments for radionuclide stabilization and/or sequestration. Foam is being assessed as a reagent carrier, and modeling tools are being developed to evaluate foam transport and reagent delivery. The delivery systems themselves are also being developed, as are geophysical methods for monitoring reagent distribution. If techniques such as these are proven to be effective, site managers will possess valuable new options for reducing the rate of contaminant transport and preventing metal and radionuclide migration to aquifers.

The fourth action area, **Mercury Characterization and Remediation**, focuses on a contaminant found across the DOE complex. Mercury presents a serious environmental challenge at the Y-12 National Security Complex (Y-12), Oak Ridge National Laboratory, and East Tennessee Technology Park, which comprise the Oak Ridge Reservation in Tennessee. It is also a contaminant of concern at the Savannah River Site and the Hanford Site. Work supported by Groundwater and Soil Remediation in this action area is based primarily at Y-12, where large-scale use of mercury resulted in extensive contamination of surface water, shallow soils, infrastructure, and the subsurface. Applied research activities include the development of technologies for treatment of waterborne mercury and contaminated soil, in situ characterization and source identification, and site conceptual modeling. The effort is expected to yield benefits both for remediation decision making and for prioritization of decontamination and decommissioning activities.

The fifth and final action area is **Remedies for Chlorinated Solvents in Groundwater and the Vadose Zone**. Progress in chlorinated solvent source zone remediation has led to increased attention on the cleanup of dilute plumes, often through MNA. However, transitions from active source-zone treatments to passive or attenuation-based approaches must be technically defensible. A first line of justification may involve demonstrating that baseline solvent remediation methods, such as soil vapor extraction (SVE), are no longer able to remove substantial contaminant mass following source zone remediation. This alone does not justify the use of MNA or other passive methods, however. Passive technologies must also be shown to prevent plume expansion, mitigate contaminant flux from the vadose zone to groundwater (e.g., through use of vegetable oil barriers) where relevant, and achieve compliance goals. Evidence of the efficacy of passive methods is particularly important for large, dilute, chlorinated solvent plumes that exist under oxic environments or other geochemical conditions that may not be conducive to rapid dehalogenation mechanisms.

A three-pronged approach is employed within the action area to foster transitioning from active to passive and sustainable remediation methods. First, tools are being developed to provide site managers with data that support attenuation-based approaches. Second, solvent attenuation via aerobic cometabolism and mechanisms other than anaerobic reductive dechlorination is being investigated. Third, training for technology transitions is being developed and offered to regulators and the EM technical community. Aspects of the last effort are performed in collaboration with the ITRC. These three endeavors will improve the ability to reach remediation closure under conditions in which persistent sources render SVE ineffective.

Table II links the FY 2010 Groundwater and Soil action areas to technical gaps identified by the National Academy of Science. The action areas explicitly address all but Gap 3, which is related to the long-term performance of trench caps, liners, and reactive barriers. However, the ASCEM initiative will help to address Gap 3 once its initial phases have been completed.

Table II. The FY 2010 Groundwater and Soil Remediation Program Plan Actively Supports Three NAS-identified Technical Gaps

<b>Gap</b>	<b>Action area</b>
1. Poorly-understood contaminant behavior	<p><i>Advanced Simulation Capability for Environmental Management (ASCEM)</i></p> <ul style="list-style-type: none"> <li>• multi-process models for open source, high-performance architecture</li> <li>• models for complex processes at scales relevant to subsurface flow and contaminant transport</li> <li>• prototype demonstrations of the computational framework at DOE sites</li> </ul>
2. Baseline remediation technologies limited by site/source characteristics	<p><i>Attenuation-based Remedies for Metals and Radionuclides in Groundwater;</i> <i>Advanced Remediation Methods for Metals and Radionuclides in the Vadose Zone</i></p> <ul style="list-style-type: none"> <li>• technical guidance, tools, and new approaches to facilitate use of attenuation-based remedies</li> <li>• alignment of site characterization and remedy selection with geochemical site evolution</li> <li>• development of minimally-invasive mechanisms and advanced monitoring strategies to emplace new reagents in deep vadose zone environments for contaminant immobilization</li> </ul>
	<p><i>Mercury Characterization and Remediation</i></p> <ul style="list-style-type: none"> <li>• new methods for mercury characterization in complex subsurface environments (e.g., fractured rock)</li> <li>• new adsorbents or reactants to enable mercury stabilization</li> </ul>
	<p><i>Remedies for Chlorinated Solvents in Groundwater and the Vadose Zone</i></p> <ul style="list-style-type: none"> <li>• mass flux-based approaches for remediation</li> <li>• transitions from active treatment to sustainable, passive approaches</li> </ul>
3. Poorly-understood long-term containment performance	<p><i>No activities are planned in FY 2010. ASCEM will contribute to addressing this gap after FY 2010.</i></p>
4. Undemonstrated long-term waste isolation by cementitious materials	<p><i>ASCEM</i></p> <ul style="list-style-type: none"> <li>• ASCEM activities (above) are complemented by those of the EM Waste Processing Program</li> </ul>

## FY 2010 BUDGET AND LEVERAGING

The Office of Groundwater and Soil is well-positioned to have a significant impact on EM cleanup and site closure life-cycle costs, currently estimated at tens of billions of dollars. The program's relatively modest FY 2010 budget is \$15 million, \$9M of which is designated for ASCEM and \$6M of which is designated for the remaining four action areas. Groundwater and Soil Remediation also leverages resources from applied research supported by the Department of Defense's SERDP and ESTCP programs. SERDP and ESTCP invest heavily in remediation technologies, particularly for chlorinated solvents and heavy metals, and the products of these investments are often directly transferrable to DOE.

Essential leveraging is also obtained from the DOE Office of Science, whose support of fundamental environmental research underpins EM technology development. The FY 2010 Office of Science program includes \$50M for its Biological and Environmental Research program, \$20M for its Basic Energy Sciences program, and \$2M for the SciDAC program, which is a source of leveraging for the ASCEM initiative. DOE's combined basic and applied

science investments in 2010 and beyond are expected to result in cost savings that vastly exceed its original research and development expenditures.

## **CONCLUSIONS**

The Department of Energy's Office of Groundwater and Soil Remediation supports technology development and demonstration for site sampling and characterization, advanced modeling, innovative remediation methods, and improved long-term performance evaluation and monitoring. Its \$15M FY 2010 program is responsive to gaps in scientific knowledge recently identified by the National Academy of Science. A new initiative, Advanced Simulation Capability for Environmental Management, has been funded to develop a state-of-the-art scientific tool and approach for understanding and predicting contaminant fate and migration in natural and engineered environments and containment systems. Complementary action areas focus on enhanced attenuation methods for metals, radionuclides, mercury, and chlorinated solvents in saturated and unsaturated environments. The program extensively leverages investments by the DOE Office of Science, the Department of Defense, and other agencies to reduce the overall risk and life-cycle costs of DOE's multi-billion-dollar environmental management mission.

## **REFERENCES**

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