

Closure End States for Facilities, Waste Sites, and Subsurface Contamination - 12543

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Abstract

The United States (U.S.) Department of Energy (DOE) manages the largest groundwater and soil cleanup effort in the world. DOE's Office of Environmental Management (EM) has made significant progress in its restoration efforts at sites such as Fernald and Rocky Flats. However, remaining sites, such as Savannah River Site, Oak Ridge Site, Hanford Site, Los Alamos, Paducah Gaseous Diffusion Plant, Portsmouth Gaseous Diffusion Plant, and West Valley Demonstration Project possess the most complex challenges ever encountered by the technical community and represent a challenge that will face DOE for the next decade.

Closure of the remaining 18 sites in the DOE EM Program requires remediation of 75 million cubic yards of contaminated soil and 1.7 trillion gallons of contaminated groundwater, deactivation & decommissioning (D&D) of over 3000 contaminated facilities and thousands of miles of contaminated piping, removal and disposition of millions of cubic yards of legacy materials, treatment of millions of gallons of high level tank waste and disposition of hundreds of contaminated tanks. The financial obligation required to remediate this volume of contaminated environment is estimated to cost more than 7% of the to-go life-cycle cost.

Critical in meeting this goal within the current life-cycle cost projections is defining technically achievable end states that formally acknowledge that remedial goals will not be achieved for a long time and that residual contamination will be managed in the interim in ways that are protective of human health and environment. Formally acknowledging the long timeframe needed for remediation can be a basis for establishing common expectations for remedy performance, thereby minimizing the risk of re-evaluating the selected remedy at a later time. Once the expectations for long-term management are in place, remedial efforts can be directed towards near-term objectives (e.g., reducing the risk of exposure to residual contamination) instead of focusing on long-term cleanup requirements. An acknowledgement of the long timeframe for complete restoration and the need for long-term management can also help a site transition from the process of pilot testing different remedial strategies to selecting a final remedy and establishing a long-term management and monitoring approach. This approach has led to cost savings and the more efficient use of resources across the Department of Defense complex and at numerous industrial sites across the U.S. Defensible end states provide numerous benefits for the DOE environmental remediation programs including cost-effective,

sustainable long-term monitoring strategies, remediation and site transition decision support, and long-term management of closure sites.

Introduction

The overall purpose of environmental remediation is protection of human health and the environment. Remedial objectives are developed based on site-specific understanding to meet this overall goal. Once remedial objectives have been met, remediation is then complete and the site has reached its end state. Typically, the most desirable end state is unrestricted use. However, the sheer mass and nature of contaminated materials at DOE sites makes it impractical to completely restore many sites to predisposal conditions. Many of these sites contain contaminated legacy facilities, waste tanks and facilities, and subsurface contamination. Current research, remediation, and clean up efforts are stove-piped and piecemealed. There is little integration and crossover of research and understanding from one technical area to another and current approaches do not provide a holistic understanding of how any one piece of the system impacts another. Thus far, there has been little effort to develop a systems-based approach to site closure. As a result:

- the long-term fate, potential for serving as a source of future environmental contamination, and disposal pathways are unknown for entombed facilities;
- multiple tank waste retrieval technologies must be deployed in a serial fashion with the ultimate goal of achieving 99% removal, regardless of expense, schedule delays, or reduction in risk;
- current allowed tank waste residuals must be $< 1\%$ and grout is the only current treatment option;
- source zone soil characteristics, flux rates, migration velocities, and spatial distribution of contaminants is grossly incomplete and has resulted in inadequate conceptual site models and overly conservative, unnecessarily expensive, and potentially ineffective remedial strategies;
- active treatment systems are inefficient and ill-suited to achieve sustainable cleanup goals within acceptable timeframes and cost;
- compliance monitoring is based on lagging indicator point-source based characterization approaches which measure concentrations at a location at snap-shots in time and cannot demonstrate that groundwater will remain uncontaminated or that contamination will remain below levels of concern in the future;
- current end states and closure requirements often are overly conservative, costly, and technically impractical.

Given the array of residual source-terms and extent of groundwater and soil contamination, an integrated, systems-level understanding that incorporates all potential source terms is needed to devise and demonstrate tractable remediation approaches. Moreover, because residual

contamination could pose a risk to human health or environment if the site were used for a different purpose, most DOE sites will require continued use restrictions such as land use controls, water use restrictions or other institutional controls after remediation is complete. As such, future end states and closure solutions must utilize integrated approaches that include potential source areas (i.e., legacy facilities, tanks, special nuclear materials, and soil) to receptors (e.g., water resources).

End states, such as unrestricted use or site closure with land use controls, drive the selection of appropriate remedial objectives. The remedial objectives, in turn, drive the type of monitoring that is conducted to measure progress towards remedial objectives. Monitoring data can also provide feedback on several other aspects of remedial progress, including the estimated timeframe for remediation. Sites with remedial timeframes estimated to be many decades, centuries, or even longer may choose to formally acknowledge the long remedial timeframes and implement a long-term management strategy. Examples of formal ways to acknowledge remedial timeframes and implement long-term management approaches include the use of technical impracticability (TI) waivers, greater risk Applicable or Relevant and Appropriate Requirements (ARAR) waivers and a variety of groundwater management/containment zone designations. The appropriate use of long-term management strategies at DOE sites has the potential to save money and use resources more effectively and sustainably. At sites under long-term management, monitoring programs must also focus on ways to detect relevant changes in site conditions that may change the conceptual site model.

Critical to DOE's ability to achieve closure for the remaining sites is defining technically defensible end states, developing and implementing systems-based remediation approaches and systems-based monitoring strategies that include potential source terms and pathways to receptors (i.e., legacy facilities, tanks, special nuclear materials, and soil and groundwater) and closure solutions that are cost-effective, sustainable, and protective of public health and natural resources.

Scope of Initiative

Using a systematic approach, the Office of Technology Innovation and Development (OTID) is focusing and integrating efforts of the Office of Science, groundwater and soil remediation, decontamination and disposition, and waste processing through established Applied Field Research Initiatives (AFRIs) to establish a consensus as to the nature and magnitude of the problems to be addressed, define realistic, defensible, and attainable end states or conditions that constitute progress or completion of cleanup, establish priorities for what work should be done, and provide the scientific and technical understanding for technology development and implementation of advanced scientific approaches to meet cleanup and closure goals of DOE sites in arid environments. Scientifically defensible approaches will be developed and implemented into the baseline to allow the risk associated with alternative facility decommissioning and deactivation (e.g., entombment), alternative waste forms, and alternative retrieval strategies, and in particular retrieval strategies that involve leaving more radionuclides in the High Level Waste (HLW) tanks to be defended and accepted in terms of the total risk presented to the public. The technical framework developed for addressing legacy source terms (i.e., waste sites and facilities) and vadose zone challenges in characterization, monitoring,

predictive simulation, and remediation that will be built and exemplified at the Hanford Site and Savannah River Site will be applicable to other sites facing similar challenges within the DOE complex, federal agencies, and local entities with responsibility for cleanup of contaminated sites, including regulatory agencies (e.g., Environmental Protection Agency (EPA), various state regulatory agencies).

The objectives of the systems-based approach are as follows:

- (1) provide the necessary scientific and technical information to assess the nature and magnitude of problems and to then assess which risks are most critical to remedy first;
- (2) provide a scientifically defensible solution to allow > 1% of tank waste residuals to be left in the tank under conditions which are protective of human health and the environment, in a manner that is acceptable to regulators;
- (3) provide the scientific basis for risk-based endpoints for waste retrieval and tank/site closure;
- (4) provide a sound technical basis for the spatial distribution of radionuclides in source terms (i.e., stabilized/entombed facilities and tank residuals) and the underlying subsurface environment (e.g., vadose zone);
- (5) account for the physical and chemical processes controlling and opportunities to retard radionuclide release from the source terms (i.e., stabilized/entombed facilities and tank residuals);
- (6) describe the fate and transport of radionuclides through the vadose zone to the point of compliance;
- (7) define mechanisms to enable addressing inherent uncertainties of environmental cleanup and responding to new information;
- (8) provide technologies and approaches for remediation, monitoring, and more efficient waste retrieval and closure.

Specific deliverables and benefits will be realized in the following four major research areas as outlined below.

Controlling Processes

- Identify and quantify key geo-stratigraphic-controlled contaminant flow pathways, that control moisture/contaminant flux and remediation amendment movement from source terms through the subsurface, in order to develop mass balance and sustainability tools that include appropriate scientific and technical descriptions of source flux and attenuation capacity specific for processes important to metal and radionuclide contamination;

- Develop methods to define the value and distribution of hydraulic properties, moisture distributions, and contaminant/co-contaminant concentrations, behavior, and fate in the subsurface and scale these parameter values to the domain discretization scale or the reactive facies scale to provide better tools for supporting site-wide assessments and decisions on environmental cleanup and stewardship;
- Understand long-term stability of remediation and cleanup end states to underpin conceptual and predictive models and provide a technical basis for transitioning from active remediation to monitored natural attenuation;
- Identify, understand, and quantify the biogeochemical and microbiological processes that control contaminant behavior, uptake, and release to provide the scientific and technology information to support CERCLA/RCRA fate and transport assessments of long-term performance for remedial alternatives.

Remediation

- Provide the foundational framework to consider the risks and challenges of remediation and cleanup activities while appropriately acknowledging technological limitations to achieving regulatory goals;
- Applied research and technology development to broaden the suite of remedies and closure options available and enhance the technical basis for evaluating remedy effectiveness, implementability, and cost;
- Develop systems-based remedial design approaches with the necessary technical underpinnings of contaminant behavior and remedial impact to reduce unintended consequences from treatment processes;
- Scientifically evaluate and justify the use natural geochemical and/or bio-geochemical processes functioning in the subsurface to stabilize contamination in place or sufficiently retard movement to achieve regulatory compliance and provide the technical and scientific framework to support alternate end states for closure through acquisition of TI waivers and/or acceptance of Monitored Natural Attenuation (MNA) for metals and radionuclides in vadose zone environments.

Monitoring & Predictive Modeling

- Develop and implement a scientific and technical framework for systems-based characterization and monitoring strategies that impact are ability to predict the efficacy of contaminant removal and treatment methods;
- Develop and deploy characterization and monitoring technologies for *in situ* characterization of complex environments including tank wastes, subsurface geochemical and hydrologic properties, contaminant movement, and remediation performance. Critical lines developments include characterization and monitoring approaches and

technologies that include early warning thresholds of unexpected behavior and flux-based monitoring.

- Develop and incorporate advanced models for tank waste into Advanced Simulation Capability for Environmental Management (ASCEM) to provide a systems approach to the tank waste clean-up and closure with the tank waste removal actions;
- Develop calibrated models and guidance to predict the mobility of risk-driving contaminants and their reactive transport for the range of waste, geochemical, and hydrological conditions prominent to natural attenuation or engineered remediation;
- Develop calibrated models for incorporation into ASCEM that allow prediction of the mobility of risk-driving contaminants and their reactive transport for the range of waste, geochemical, and hydrological conditions prominent to natural attenuation or engineered remediation;
- Reduce remedial design development and implementation times by applying simulation capabilities that facilitate development and utilization of remediation technology performance modeling to support Feasibility Studies;
- Provide credible predictive models that depict natural subsurface dynamics, contaminant behavior, and remedial performance at spatial and time scales of importance are necessary to make defensible remedial decisions and achieving cleanup goals.

Facility Disposition

- Understand the chemical, biological, and physical interactions of building materials, construction debris, decontamination processes, contaminants, and tank waste residuals over time to produce a scientific basis for determining the realistic, defensible, and attainable end states;
- Develop technically defensible Performance Assessments (PA) to allow the risks associated with alternative facility decommissioning and deactivation (e.g., entombment), alternative waste forms, and alternative retrieval strategies, and in particular retrieval strategies that involve leaving more radionuclides in the HLW tanks to be evaluated in terms of the total risk presented to the public;
- Understand the fundamental chemical, biological, and physical interactions between contaminants and building materials to provide significant advances in decontamination methods and technologies to enable technology development of advanced approaches capable of removing contaminants from surfaces and from within porous materials found in surplus DOE facilities and formulations for in-situ entombment of high activity radionuclides.

Impact

Moving forward, organization of the OTID program into four strategic initiatives such as this will maximize synergistic relationships, resources, and impact. This initiative seeks to advance EM's scientific understanding, technical knowledge, and technologies. This type of structure allows funding to be leveraged in a manner that advances large research activities forward in a timely manner and allows for transformational solutions for Department site cleanup and closure. Moreover, the structure and scope of this initiative removes the traditional "stovepipes" in the areas of 1) waste processing, 2) groundwater and soil remediation, 3) D&D, and 4) nuclear materials by taking a comprehensive view of the critical problems and aligning the components required to address these problems under a single vision (i.e., defined problem statement). Having a single vision and focus within each initiative provides the framework required for a systems-level approach to cleanup. This also allows OTID the flexibility to address emerging issues while simultaneously working on long-range solutions to EM's most complex challenges while realizing near-term impacts.

This initiative will develop and implement scientifically defensible approaches to allow the risk associated with alternative facility D&D (e.g., entombment), alternative waste forms, and alternative retrieval strategies, particularly retrieval strategies that involve leaving more source term in the HLW tanks to be defensible and acceptable in terms of the total risk presented to the public. The technical framework developed for addressing legacy source terms (i.e., waste sites and facilities) and vadose zone challenges in characterization, monitoring, predictive simulation, and remediation that will be built and exemplified at the Hanford Site and Savannah River Site will be applicable to other sites facing similar challenges within the Department complex, federal agencies, and local entities responsible for cleanup of contaminated sites, including regulatory agencies (e.g., EPA, various state regulatory agencies).

Critical deliverables from this initiative will include frameworks for remediation, tank and site closure, and transition decisions supporting D&D, waste sites and facilities, and groundwater and soil, and compilation of tank and subsurface remediation technology, closure, and transition decisions guidance. This initiative will increase scientific, public, and regulatory acceptance of systems-based monitoring strategies and approaches to provide holistic understanding supporting transition decisions and site closure. This initiative will also improve scientific, public, and regulatory acceptance of remediation and cleanup strategies supporting achievable end states.