Overview of Impacts of Technology Deployment on the Mission of the Department of Energy Office of Environmental Management - 11535

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ABSTRACT

The Environmental Management (EM) mission is to complete the safe cleanup of the environmental legacy brought about from five decades of nuclear weapons development and government-sponsored nuclear energy research. The EM program has embraced a mission-completion philosophy based on reducing risk and environmental liability over a 40-50 year life-cycle.

The Department has made great progress toward safely disposing of its legacy nuclear waste. EM Research and Development (R&D) program management strategies have driven numerous technology and engineering innovations to reduce risk, minimize cleanup costs, and reduce schedules. Engineering and technology investments have provided the engineering foundation, technical assistance, approaches, and technologies that have contributed to moving the cleanup effort forward. These successes include start-up and operation of several waste treatment facilities and processes at the sites. Funding for the R&D of these facilities has come from several sources, primarily through site operating contracts, site design and construction contracts, and the Office of Technology Innovation and Development (OTID), and its predecessor technology development offices. Some funding has also been provided by other Department of Energy (DOE) offices, including Office of Science (SC).

INTRODUCTION

Successful deployment of technologies is often reliant on a blend of efforts between inventors, applications-oriented scientists and engineers, and site-contractor engineers. Sustained support by EM in filling the technology gap between invention and deployment is vital to the success of the EM mission, since the maturation of these technologies often stretches over several years. The descriptions below demonstrate examples of the successful bridging of this gap to enable implementation of a new or improved technology. Maintaining a pipeline of new technology innovations, coupled with an active program focused on deployment and tied closely with the sites, will ensure additional successes. The resulting outcome of technology innovation and applied research will be reduced risk, minimized cleanup costs, and reduced completion schedules. This summary of successes from EM R&D spending covers the past ten years. Technologies are considered a success if they have been deployed on contaminants of concern to the Department, or the technology is matured and demonstrated to the point where a treatment facility is under construction.

Many of the successes were funded through multiple sources; often beginning with the OTID, leveraging with other agencies and ending with the sites. This beneficial hand-off enables development of technologies that transform fundamental science into viable solutions to address site needs. The OTID is the critical link that identifies key experts and ideas, provides resources, and matures solutions to a point where they can be transitioned to a site for implementation. This process is crucial because it continuously advances the EM mission and provides enduring technical capabilities to meet EM goals. The sections below outline the status and recent success in the various OTID program elements – tank waste, groundwater and soil, and deactivation and decommissioning – and provide examples of promising future efforts that are slated for near term deployment.

TANK WASTE STATUS

Tank waste is the most significant environmental, safety, and health threat in DOE and is the largest cost element for EM. There are currently almost 90 million gallons of radioactive waste being safely stored in 230 tanks at DOE's Hanford, Savannah River, and Idaho sites. The chemistry and forms of the wastes vary widely, as do the tank configurations and geometries. Processing this radioactive tank waste has long been recognized as one of the most technologically complicated efforts in the Department. Retrieval, processing, and immobilization involve highly coordinated process steps that often require tailored solutions based on the specific waste, tank conditions, and situation. The current baseline for the treatment and disposition of tank waste has a life-cycle cost range of $88 billion to $117 billion, (*Roadmap; EM Journey to Excellence*, draft, 2010). The tank waste program presently is forecast to have a remaining duration of more than 30 years.

The Defense Waste Processing Facility (DWPF) at Savannah River Site (SRS) has been operating since 1996, and has produced over 2500 vitrified waste canisters, primarily of sludge waste. EM investments developed the science and engineering to design and operate this plant, and continued investments have kept it operating and improving. Pretreatment of aqueous tank wastes at Savannah River Site is being performed with the Actinide Removal Process and the Modular Caustic-side Solvent Extraction Unit, which started operations in 2008. These operating facilities utilize technologies developed with both SC and EM funding, with R&D performed at multiple DOE laboratories. The technology has also provided the design basis for a much larger scale facility, the Salt Waste Processing Facility, currently under construction at Savannah River Site. Continued investments by EM are expected to yield improved performance at both facilities.

The Waste Treatment Plant at Hanford is under construction, and EM investments have developed the technologies that provided the design basis and will be used to treat and vitrify the tank wastes at Hanford. The vitrification plants at Hanford build off of the knowledge and experience at the Savannah River Site, although the wastes are typically more varied and challenging. Ongoing investments in pretreatment technologies and vitrification research will improve waste loading, decreasing the life cycle cost and schedule. EM investments also developed a new ion exchange resin that will be used in the facility to decontaminate the aqueous wastes. This improved technology will save considerable schedule and costs throughout the lifetime of the facility.

The Integrated Waste Treatment Unit for Sodium Bearing Waste at Idaho National Laboratory is nearly ready for start up. EM investments in the Fluidized Bed Steam Reforming process technology provided the design basis and will be used to immobilize the tank waste.

EM has also invested in technologies to improve retrieval of waste from storage tanks, and these techniques are currently being used at both Savannah River Site and Hanford. SRS typically uses bulk waste removal with pumps, followed by chemical cleaning; whereas Hanford typically uses modified sluicing, vacuum retrieval, and other techniques. Ongoing investments in retrieval technologies are yielding improved techniques with each tank that is retrieved.

TANK WASTE R&D SUCCESSES

Recirculation Pump for Glass Melter – EM R&D investments developed a technology for improved mixing of the glass inside the DWPF melter. Due to the viscous nature of the glass and melter configuration, thorough mixing of the molten glass is challenging. This pump increases the mixing of the molten pool of glass, increasing the throughput of the melter by approximately 10%. A patent was issued for this technology, which has application in both other DOE waste melters, as well as commercial melters.

Strategic High Level Waste Glass Frit Formulation for DWPF – EM R&D developed and implemented a unique system by which glass frit compositions can be tailored and optimized for each high level waste sludge batch vitrified at the SRS DWPF. The frit optimization strategy ensures that glass waste forms meet all processing, performance and regulatory constraints, while maximizing waste throughput to speed site cleanup missions. The implementation of this process has resulted in waste loading increases from 25% to 38%, and/or significant reduction in canister fill time (melt rate). Overall, waste throughputs have significantly improved, allowing DWPF to exceed contractual goals in addition to reducing the overall life cycle costs. This program is a continuous effort as waste compositions change and further process improvements are developed. This eliminated the need for more than 1000 canisters, reducing transportation and Repository disposal costs by over $500 million.

Enhancements to the Process Control Strategy for DWPF – EM R&D developed and supported implementation of several alternative process control models that have allowed significant improvements in waste loading and melt rate for the DWPF without compromising product quality. In addition, implementation of these models has alleviated tank farm constraints associated with sludge washing, contributing to significant operating cost savings. This program is a continuous effort as waste compositions change and further process changes occur.

Cesium Removal Demonstration and Disposal for Oak Ridge National Laboratory (ORNL) – A cesium removal demonstration process was deployed at ORNL to remove Cs-137 and Sr-90 from over 200,000 gallons of Low Level Liquid Waste. Crystalline silicotitanate, an inorganic media developed by EM, with very high selectivity for cesium, was used to treat the wastewater [1]. EM sponsored R&D developed a glass formulation to accommodate this unique ion exchange media into a final waste form, and vitrified the spent media from the treatment process. This research enabled treatment and disposal of this tank waste at ORNL.

Sampling of High Level Wastes – EM R&D has supported development and deployment of numerous unique sampling devices, tools, and techniques to remotely sample contents of tanks, evaporators, and other waste processing system components. This is a continuous development process as new sample configurations and tank or process conditions change.

Real Waste Low Temperature Aluminum Dissolution – EM sponsored R&D that demonstrated that mixing caustic with High Level Waste sludge while maintaining a temperature of 55-65 ºC provided an effective means of removing aluminum from the sludge [2, 3]. The purpose of this was to reduce the quantity of sludge requiring vitrification at the DWPF. This process was implemented at SRS for DWPF Sludge Batches 5 and 6, and avoided costly upgrades to the tank to allow for higher temperature application. Performing this aluminum removal process reduced glass production at the DWPF by more than 300 canisters, saving more than $150M.

Fernald Silos Waste Retrieval and Processing - Waste from the processing of uranium ore (240,000 ft^3) in two 80-foot diameter silos, was removed, treated, and packaged using a remote handling system. EM invested in R&D for grout formulations and selection and testing of innovative retrieval, characterization, and closure technologies. This assistance significantly reduced project risks and contributed to ensuring early Fernald closure. The ~$2 million investment resulted in a direct cost savings of $75 million.

Corrosion Control Technologies to Mitigate Risk of Aging DOE Facility Infrastructure -DOE-EM facility infrastructure has been in-service for over 50 years and it is anticipated that these structures will be needed for several more decades. EM has supported development and understanding of the corrosion control and corrosion mitigation strategies which are being implemented for DOE high level waste tanks at both SRS and Hanford [4]. The technologies developed for corrosion control have been a key to ensuring buy-in from stakeholders for continued utilization of aging high level waste tanks, resulting in significant cost avoidance of ~$100M for each newly constructed tank.

GROUNDWATER & SOIL STATUS

The DOE complex represents one of the largest, most complex, and formidable subsurface environmental restoration challenges in the world. Groundwater, soils, and sediments at DOE sites are contaminated with radionuclides, metals, and/or organics. DOE has estimated that about 1.8 billion m^3 (475 billion gallons) of contaminated groundwater and 75 million m^3 (2.6 billion cubic feet) of contaminated soil need to be addressed as part of the complex-wide subsurface cleanup. The cost to complete environmental restoration with the existing baseline technologies is estimated to be approximately $22 billion over a 70-year period [5].

Although EM has been successful in closing and treating many sites within the complex, many challenges remain. As is evident by the Fernald and Rocky Flats Cleanup Projects, implementing science-, engineering-, and technology-based solutions has traditionally lowered life-cycle cost by accelerating the cleanup schedule, improving worker safety, reducing environmental risk, and offering better, safer, and cheaper alternatives to the baseline technologies. The subsurface problems that remain are clearly some of the most complex ever encountered by the technical community, especially at the larger sites such as Savannah River, Oak Ridge, and Hanford. For example, the Savannah River and Hanford sites have extensive groundwater plumes containing ^{90}Sr, uranium isotopes, ^{129}I, tritium, nitrate, and organic solvents at concentrations above applicable standards. The Oak Ridge Reservation has extensive contamination of the environment, including soils, groundwater, surface water, and biota with mercury. Additionally, significant amounts of other contaminants were released into the environment, including radionuclides (various isotopes of U, ^{90}Sr, ^{239}Pu, ^{60}Co, ^{99}Tc, ^{232}Th, ^{137}Cs, etc.), heavy metals (Pb, Cr, Cd, Ni, and Co), nitrate, various inorganic compounds, and organics, such as polychlorinated biphenyls (PCBs), solvents, and pesticides. Throughout the nation, these releases have contaminated the underlying soils and shallow groundwater and have created persistent source zones of contaminants and large groundwater plumes that sometimes discharge to nearby creeks and water bodies. The Hanford Site has subsurface contamination concentrated in two locations: the Columbia River Corridor and the Central Plateau. These areas include soils and groundwater contaminated with radionuclides (various isotopes of U, ^{90}Sr, ^{99}Tc, ^{129}I, etc.), nitrate, carbon tetrachloride, inorganic compounds, and organics. In addition the Central Plateau is characterized with a thick soil layer (a “deep vadose zone”) which is challenging to access and treat.

An overarching challenge, the need for improved modeling and simulation capability, was recently identified by scientists from the National Academies as a critical need and a necessary applied science target for the future. EM is investing the expertise of the DOE national laboratory community, universities, and industry in developing the next generation of computer simulation capability for environmental management and performance assessment. This effort has been named ASCEM (Advanced Simulation Capability for Environmental Management). The goal of this major multiyear effort is to overcome current limitations in modeling to improve decisions, reduce remediation costs, and improve environmental stewardship.

GROUNDWATER & SOIL R&D SUCCESSES

<u>Implementation of Groundwater Base Injection System at SRS F-Area</u> – EM R&D developed and demonstrated a base injection system for remediation of groundwater at SRS’s F-Area. This process allowed SRS to obtain regulatory approval to shut down a pump & treat system which had operated for six years at a cost of $1 million per month and generated thousands of cubic yards of solid waste. [6]

<u>Monitored Natural Attenuation/Enhanced Attenuation for Chlorinated Solvents</u> – Large plumes of chlorinated solvents in aerobic groundwater are present at most DOE sites. EM field research has demonstrated that processes like aerobic cometabolism and abiotic degradation of solvents in the presence of oxygen are active in contaminant groundwater plumes throughout the DOE complex. This research provides, for the first time, a basis for a path to closure for these plumes. This work was formalized by collaboration with regulators who produced a technical guidance document [7] on enhanced attenuation (EA). The work at the field sites is typically done in cooperation with the EM organizations performing the clean-up so that leveraged research costs are minimized and the potential for acceptance of the resulting technologies is maximized.

Attenuation-based Remedies for Metals and Radionuclides – Significant advances are beginning to be achieved in understanding and advancing the applicability of natural attenuation for metals and radionuclides through applications of cutting edge research, development of simplifying scenarios, partnering with regulators and stakeholders, and strategic funding of research on high priority "technical targets." This work is being done at the Savannah River F-Area Field Research Site and the Hanford Deep Vadose Zone Field Research Site, with participation of universities and industry. [6]

Treatability Study for Edible Oil Deployment for Enhanced cVOC Attenuation at SRS T-Area – EM R&D developed and performed a successful demonstration of an Edible Oil Deployment for chlorinated volatile organic compounds (cVOC) remediation at the SRS T-Area. This success enabled regulatory approval to permanently shut-down the T-1 Air Stripper in favor of this cost-effective enhanced attenuation (EA) approach. [8]

Remediation of Hexavalent Chromium, Strontium, Carbon Tetrachloride, and Uranium in Groundwater – EM supported a diverse set of actions to support the identification of chromium sources and the removal/immobilization of subsurface chromium contamination at the Hanford Site in Washington. Several potential technologies were identified and tested. Those that proved successful (e.g., the chromium source characterization tools, phosphate treatment of uranium and strontium, hydrolysis of carbon tetrachloride, etc.) are being considered or have been incorporated into regulatory agreements for deployment – resulting in future cost reductions and improvement in environmental protection [9].

Partnerships -- In these other topic areas, DOE EM is partnering with state and federal regulators through the Interstate Technology and Regulatory Council (ITRC) and the Federal Remediation Roundtable. DOE EM is also successfully collaborating with the Department of Defense and other federal partners as well as with industry through the Advanced Remediation Technologies (ART) and Small Business Innovative Research (SBIR) programs. A recent highlight of EM partnerships was the development by ITRC, with concurrence by all 50 states, of new technical and regulatory guidance to support implementation of innovative, protective and cost effective environmental cleanup strategies such as "Enhanced Attenuation." These successes have been solidified by active outreach including: training to scientists and contractors at EPA regional offices, training at the International Conference on Remediation of Recalcitrant Contaminants, and the inauguration of ITRC internet training cycle on Enhanced Attenuation of Chlorinated Organics.

Technical Assistance -- EM provides technical assistance to bring technology to bear in overcoming specific groundwater and soil hurdles being faced on the ground in the DOE complex. Highlights in this area include support at the Y-12 Plant at Oak Ridge to address mercury challenges, Pantex, Mound, Sandia, Los Alamos, Livermore, Ashtabula, Kansas City, Brookhaven, Hanford, Paducah and Portsmouth to address radionuclides and solvents. To date, technical assistance efforts have generated significant cost savings and return on investment. For example, the technical assistance efforts at Fernald alone resulted in total estimated cost savings of over $94 million with an investment of less than $4 million and technical assistance efforts at Mound resulted in total estimated cost savings of over $29 million with an investment of about $2 million. Similar return on investment factors have been realized in a number of cases where full scale remediation was optimized based on utilizing the technologies emerging from the DOE EM field research program and acceptance of the technologies by regulators and stakeholders.

DEACTIVATION & DECOMMISSIONING STATUS

The cost of Deactivation and Decommissioning (D&D) of facilities is conservatively estimated at $20-30 billion. EM's current life-cycle scope comprises over 3000 facilities, including over 1000 nuclear and radioactive buildings located across the DOE complex [10]. The portfolio includes multiple nuclear production reactors, over 100 test and research reactors, multiple-football field size gaseous diffusion plants, chemical processing plants, fuel and weapons component fabrication facilities, canyons and radionuclide separations facilities, laboratories, hundreds of miles of buried pipelines, and a myriad of other contaminated facilities. A large number of facilities to be decommissioned in the DOE complex are one-of-a-kind and/or unique to DOE with unprecedented scope and complexity. In many instances the needed technologies are yet to be developed or will require significant re-engineering to be adapted to meet Department needs. With the more complex D&D projects scheduled into the out years, an opportunity exists to address needed technical improvements and advancements to achieve cost and schedule expectations.

With EM's current focus on accelerated foot print reduction, highly contaminated and, in some cases, structurally unsound facilities will be decommissioned. D&D of these facilities presents significant new challenges to maintain worker safety and effective project execution. Transformational technologies and technical approaches are needed to meet the Department's zero accident goals and impact EM lifecycle cost. D&D is poised for strategic investments in the development of novel, innovative technologies to address the unique site D&D challenges and enable site cleanup.

DEACTIVATION & DECOMMISSIONING R&D SUCCESSES

<u>RADBALL</u> - The RadBall is a technology initially developed by the UK National Nuclear Laboratory and further matured as a joint project with EM. The system has no moving parts and uses a Computer Tomography (CT) scanner to provide semi-quantitative information on the spatial distribution of contamination in contaminated rooms and hot cells to enable planning for D&D activities. The technology uses a radiosensitive polymer encased in a tungsten collimator. The absence of electronics allows the system to be used in high radiation environments. A collaborative effort has led to development of remote deployment and spatial orientation systems to reduce the risk to workers, as well as the development of more sensitive polymers, an improved collimator, and a portable CT scanning system to allow field analysis of information following deployment. The system has been used in contaminated areas at SRS and Oak Ridge. [11]

<u>Laser Imaging of Hazardous Facilities</u> - Developing 'as-found' drawings of old and hazardous facilities exposes workers to potentially serious hazards, while the absence of such drawings seriously impedes D&D planning. EM-supported R&D developed a system using a commercially available 3-D laser imaging system combined with a simple robotic deployment system to obtain high resolution images of a potentially hazardous facility. The system is

remotely operated and provides visual and digital imagery of the facility space that can input to 3-D Computer Aided Design systems, achieving highly accurate spatial resolution images. The system was deployed in the SRS P Reactor Purification room. [12]

FUTURE R&D SUCCESSES

The nature of many of the remaining cleanup challenges, several of which are one-of-a-kind and unique to DOE, requires a strong and responsive applied research and engineering program. To identify technology needs, and approaches to reduce technical risk and uncertainty, EM has developed the *Environmental Management Research and Development Plan*. The plan details a strategy for research and development initiatives to support radioactive tank waste processing, groundwater and soil remediation, facility deactivation and decommissioning technologies, used (spent) nuclear fuel management, and challenging materials disposition.

Several technologies have been matured to a level where they are included in efforts at the sites, but have not yet proceeded to construction. It is anticipated that maturation of these technologies will continue, and they will be successes in the near future:
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<u>Small Column Ion Exchange</u> – This in-tank ion exchange process is designed to decontaminate High Level Waste without building a separate treatment building. This process was designed as a lower cost alternative for removing radioactive cesium from the liquid fraction of tank wastes at SRS. A similar version of this process is also under consideration at Hanford. The process uses an ion exchange media, and a rotary Microfilter, also developed by EM. The <u>Rotary Microfilter</u> is an extensively modified commercial filtration technology, with patented redesigned components for use in highly radioactive and harsh chemical environments.

<u>Modified Monosodium Titanate (mMST)</u> – This new titanium-based sorbent material is similar in composition to monosodium titantate (MST) currently in use at the SRS Actinide Removal Process, but exhibits significantly improved performance. This material removes radioactive strontium and actinides (such as plutonium and neptunium) from liquid High Level Waste. The plutonium removal efficiency of the baseline process is a dominant factor limiting the operational capacity in two pretreatment facilities, the Actinide Removal Process and the under-construction Salt Waste Processing Facility. This new material is expected to significantly improve throughput in these facilities.

<u>Improved Glass Waste Loading at Hanford Waste Treatment Plant</u> - EM continues to support research efforts to develop improved glass formulations for problematic wastes at Hanford. It is anticipated that this effort will identify formulation improvements that can increase waste loading, eliminating the need for many canisters, reducing production, transportation, and disposal costs. These improved formulations will be incorporated into the process in time to support WTP start up.

<u>Grout Formulations for Reactor Vessel Closure</u> - Filling of vessels containing significant volumes of aluminum using standard grout formulations creates hazards during closure actions. Reactions between the aluminum and the highly alkaline grouts results in the production of

hydrogen which can create explosion hazards. EM-sponsored R&D developed a near-neutral pH grout formulation for the closure of a reactor vessel at SRS.[13] This formulation does not react with the aluminum components and eliminates the risk associated with excessive hydrogen production. It is planned for deployment at SRS in 2010 for closure of the P-Reactor vessel.

Strippable Coating Validation for WIPP Disposal - EM supported development of Decon Gel by a vendor, and it has proven to be a highly effective strippable decontamination agent for contaminants of concern. As part of the Plutonium Fabrication Facility (PuFF) decommissioning at SRS, this product was planned for use in the decontamination of ^{238}Pu in the Hot Cells. Since the residue will be containerized in preparation for disposal at the WIPP facility, the potential existed for generation of Volatile Organic Carbon, which could prohibit its disposal. EM R&D supported testing of the product, resulting in approval for disposal as TRU waste at WIPP, and is expected that it will be used in 2011. This research significantly increases the utility of this highly effective product.

Innovative In-Situ Treatments for Radionuclides in Groundwater – Several geochemical treatment technologies are in development and being readied for deployment. These methods are used in the subsurface, *in situ*, to reduce the mobility, toxicity or solubility of specific radionuclides. The next generation of *in situ* treatments relies on reagents that specifically interact with a target contaminant. For example an injectable solid silver chloride amendment developed by SRNL for treatment of ^{129}I will be deployed at the F-Area Seepage Basins site in late 2011. Silver chloride has a low solubility, but it is several orders of magnitude higher than silver iodide. Hence, the amendment sequesters ^{129}I by promoting precipitation of silver iodide. The amendment will be injected just upgradient of the gates in the existing funnel-and-gate treatment system. The recently installed funnel and gate system treats most of the radonuclides in the contaminated groundwater, but not ^{129}I, by raising the groundwater pH using sodium hydroxide and carbonate buffer. Two alternative bases, solid magnesium hydroxide and disodium silicate, will be tested at the F-Area Field Research Site beginning in 2011. Particulate magnesium hydroxide can be used in targeted injections and has a relatively high buffering capacity per gram. Use of disodium silicate results in precipitation of amorphous silica that may sequester contaminants by sorption or precipitation of silicate phases. Both of these alternatives reduce the potential for uranium complexation associated with carbonate ions.

Quick-Win Technologies for Reducing Mercury Releases from the Oak Ridge Y-12 Plant - Between 1953 and 1983, over 200,000 pounds of mercury were released to the environment from the Y-12 Plant. For the past thirty years, Oak Ridge has actively pursued a program to decrease mercury release to the surrounding environment by isolating and removing sources and by treating discharges if isolation and/or removal were ineffective or infeasible. These past actions lowered mercury discharges by over 90% but additional decreases are required to protect the stream and reduce fish tissue concentration to acceptable levels. EM-32 research has enhanced the conceptual model for mercury at Y-12 and has identified “quick-win” opportunities to deploy innovative technologies that will lower mercury releases and better characterize mercury sources/behaviors. The technologies and strategies that are being developed for deployment include: 1) use of a heated membrane interface probe for delineating mercury sources in soil, 2) soil gas mercury surveys and improved mapping/modeling techniques, 3) application of low cost treatments such as chemical reduction of mercury followed by air stripping (or treatments using new types of mercury sorbents), and 4) rerouting of supplemental water flow to eliminate mercury contact/flushing. The performance and safety of these "quick win" activities is currently being evaluated and if confirmed these technologies are slated for deployment in FY 2011-2012.

FUTURE R&D PROGRAM

The Department of Energy's Office of Environmental Management is committed to reducing the life-cycle resources required for cleanup of legacy nuclear waste and aging infrastructure. Achieving this goal requires a multi-faceted program that focuses R&D both on support and maturation of technologies that support site baselines, and on approaches and technologies that will transform (reduce) risks, costs, and schedules.

Site baseline support is generally enabled through site contracting mechanisms which focus research on facility design, accommodating changes, and operational improvement needs. Conversely, part of the mission of EM's Office of Technology Innovation and Development is to provide technical solutions where none exist, improve solutions that enhance safety and operating efficiency, and create technical alternatives that reduce programmatic risks to technical baselines. This integrated approach leverages investments in scientific and technological research to reduce technical barriers and uncertainty. This will result in more timely treatment and disposal of nuclear materials, which reduces the risk to workers and the public.

While much has been accomplished by EM in waste remediation, much work remains to be done. Maturation of solutions to meet the technical challenges often takes several years to reach deployment. A continuous, robust technology development program is needed to sustain the "pipeline" of solutions. This was also observed by the National Academy of Science report *Advice on the Department of Energy's Cleanup Technology Roadmap: Gaps and Bridges*: "The complexity and enormity of EM's cleanup task require the results from a significant, ongoing R&D program so that EM can complete its cleanup mission safely, cost-effectively, and expeditiously." It is evident that R&D needs to remain a part of the focus of EM until the mission is complete.

REFERENCES

1. J. F. Walker, Jr., T. E. Kent, *Wastewater Triad Project: Final Summary Report* ORNL/TM-2001/129, Oak Ridge National Laboratory, Oak Ridge, TN, (2001).
2. M.S. Hay, J.M. Pareizs, C.J. Bannochie, M.E. Stone, D.R. Click, D.J. McCabe, *Characterization and Aluminum Dissolution Demonstration with a 3 Liter Tank 51H Sample,* WSRC-STI-2007-00697, Savannah River National Laboratory, Aiken, SC, February 2008
3. S.H. Reboul, M.S. Hay, K.E. Zeigler, M.E. Stone, *Tank 12 Sludge Characterization and Aluminum Dissolution Demonstration*, SRNL-STI-2009-00180, Savannah River National Laboratory, Aiken, SC, March, 2009
4. K. Subramanian, M. Maryak, K. Boomer, B. Wiersma, *Savannah River Site and Hanford Double Shell Tank Integrity Program*, SRR-STI-2010-00291, Savannah River Remediation, Aiken, SC, May, 2010.

5. NRC (National Research Council), 2009. Technical and Strategic Advice for the Department of Energy, Office of Environmental Management's Development of a Cleanup Technology Roadmap: Interim Report. The National Academies, National Research Council Nuclear and Radiation Studies Board, Washington DC. (available at http://www.em.doe.gov/pages/EngineeringTechnologyNAS.aspx)
6. M.E., Denham, and K.M. Vangelas, 2008. Biogeochemical gradients as a framework for understanding waste-site evolution. Remediation, v. 19, p. 5-17.
7. ITRC (Interstate Technology and Regulatory Council), 2008. Enhanced Attenuation: Chlorinated Organics: Technical and Regulatory Guidance. ITRC, Washington DC. Available at: http://www.itrcweb.org/Documents/EACO-1.pdf .
8. B.D. Riha, B.B. Looney, J.V. Noonkester, W.K. Hyde and G.C. Blount, 2008. Moving Beyond Pump and Treat Toward Enhanced Attenuation and Combined Remedies: T-Area, Savannah River Site. In Proceedings of the Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, May 2008, Monterey CA.
9. B.B. Looney, D.S. Kaback, E.J. LeBoeuf, J. Rossabi, K.L. Skubal, D.L. Cocke and P.C. Deutsch, 2008. Supplemental Columbia River Protection Activities at the Department of Energy Hanford Site: 2008 Technical Review, SRNL-STI-2008-00424, U.S. Department of Energy Office of Scientific and Technical Information, Oak Ridge TN. Available at: www.osti.gov .
10. DOE (U.S. Department of Energy). Facility Deactivation and Decommissioning, D&D Program Map, 2009 Edition. Office of Deactivation and Decommissioning/Facility Engineering, U.S. Department of Energy, Washington, DC. 2009.
11. E. Farfan, J. Gladden, T. Foley, S. Stanley, C. Holmes, R. Mills, P. Knight, D. Mackenzie, T. Jannik, M. Oldham, C. Clift, A. Thomas and J. Adamovics. Control Testing of the UK's National Nuclear Laboratory RadBall at Savannah River National Laboratory. Waste Management Symposium 2010, Phoenix, AZ.
12. R. Fogle, D. Karapatakis, J. Gladden, T. Long, J. Santos and S. Frush. Robotically Deployed Laser Imaging for Facility Dimensional Characterization. Waste Management Symposium 2009, Phoenix, AZ.
13. M.G. Serrato, C.A. Langton, J.B. Gladden, J.T. Long, J.K. Blankenship, A.P. Szilagyi, G.R. Hannah and R.B. Stubblefield. Considerations for Grout Formulations for Facility Closures using In Situ Strategies. Paper 40273. Proc. 13th International Conference on Environmental Remedation and Radioactive Waste Management. October 2010 Tsukba, Japan.