Office of Deactivation and Decommissioning Research and Development Program for Fiscal Year 2011 - 11533

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ABSTRACT

The U.S. Department of Energy's (DOE) Office of Deactivation and Decommissioning (D&D) Research and Development (R&D) program supports the identification, development and timely deployment of adaptive and transformational technologies needed for the safe closure of nuclear, radiological and industrial DOE facilities. This program has linked its current and future developmental efforts with the National Research Council's focus areas for D&D and input from the field. Technology alternatives, technical assistance, and applied research activities within the D&D R&D program are selected and prioritized based on ability to yield the best cost, schedule and safety benefit to the D&D operations. The D&D R&D Program is supported in five primary areas: Characterization, Equipment Removal and Dismantlement, Personal Protective Equipment and Worker Protection, Decontamination, Robotics and Intelligent Systems and End States—In Situ Decommissioning.

This paper discusses the approach and strategy described in the EM R&D Plan for developing technologies in support of safe facility closure and provides an overview of the FY 2011 high priority tasks.

INTRODUCTION

The Deactivation and Decommissioning (D&D) of facilities represents the second highest cost center in the EM Program and is conservatively estimated at $30-40 billion. EM's current life-cycle scope comprises over 3000 facilities, including over 1000 nuclear and radioactive buildings. These facilities account for close to 25 percent of the DOE's total buildings and other structures, and nearly 47 percent of the DOE's replacement plant value. The portfolio includes nuclear production reactors, test and research reactors, gaseous diffusion plants, chemical processing plants, fuel and weapons component fabrication facilities, canyons and radionuclide separations facilities, laboratories, thousands of miles of above ground, embedded, and buried pipelines, and a myriad of other contaminated facilities, process systems, and equipment. Many of the facilities to be decommissioned 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 DOE needs. With the more complex D&D projects scheduled into the out years, an opportunity now exists to address technical needs and advancements to improve safety and cost and schedule expectations.

A 2001 report of the National Research Council of the National Academies [1] observes: "There are strong safety and economic incentives for developing and using innovative D&D technologies that may be achieved through scientific research." This report identifies four research areas that could contribute to improving D&D operations: 1) characterization of contaminated materials, 2) decontamination of equipment and facilities, 3) remote intelligent systems, and 4) end state definition for facility D&D.

In its 2009 *Advice on the Department of Energy's Cleanup Technology Roadmap, Gaps and Bridges* [2], the National Research Council concludes that "existing knowledge and technologies are inadequate for EM to meet all of its cleanup responsibilities in a safe, timely, and cost-effective way" and acknowledges

its 2001 report [1] in prioritizing three D&D areas for scientific and technology improvement: 1) characterization, equipment removal, and dismantlement using robotic and remote systems; 2) improved personal protective equipment (PPE); and 3) improved decontamination methods.

The existing paradigm of D&D as a low priority and low-tech or no-tech operation that can be performed by brute force must be overcome and replaced by a more technically sound approach. As the National Research Council's 2001 report [1] states, "while current D&D technologies probably can be made to work in the D&D of DOE facilities, there are opportunities to do the job more safely and effectively by developing and using new technologies." Though footprint reduction has been achieved using the low tech/brute force approach, EM's current focus on accelerated footprint reduction of highly contaminated and, in some cases, structurally unsound facilities will present significant new technological challenges to maintain worker safety and effective project execution.

Following a few years of minimal funding yet significant advances, D&D is poised for investment to build up and evolve the development of transformational technologies and new approaches needed to execute high-cost and high-risk D&D projects while meeting the DOE's goals of zero accidents and reduction of the EM life-cycle cost. A strategic long-term plan is being developed to create a logical case and vision for federal government investments in technology development and deployment, technical assistance, and applied research. This plan will address the five focus areas in Table I and emphasize three major goals: 1) reducing technical and safety risks in current site baselines; 2) reducing costs by accelerating cleanup; and 3) anticipating and providing alternative technologies and practices for more efficient and cost-effective D&D.

Table I. Deactivation and Decommissioning R&D Areas

D&D Focus	Statement of Technical Gap
Characterization, Equipment Removal and Dismantlement	D&D work relies on manual labor for facility characterization, equipment removal, and dismantlement.
Personal Protective Equipment	Personal protective equipment tends to be heavy and hot and limits movement and productivity of workers.
Decontamination	Removing contamination from building walls, other surfaces, and equipment is slow and ineffective.
Robotics and Intelligent Systems	Major opportunities for reducing risks to workers lie in the development of intelligent remote systems that can substitute for human workers in hazardous areas
End States—In situ Decommissioning (ISD) Technologies	The definition of End States for D&D facilities will have a major impact on cost, schedule and risk to the public, workers and the environment

Notably, several of these technology focus areas, and the specific technology initiatives, are mutually dependent and supportive. For example, the deployment of the characterization, removal and dismantlement tools into hazardous environments will, in many cases, be dependent on the successful development of robotic platforms that can deliver the tools to the work location. Similarly, the development of these technologies can significantly improve worker safety and influence the requirements for advanced PPE for workers.

INTEGRATION OF RESEARCH & DEVELOPMENT AND D&D STRATEGY

Development of strategic initiatives for the D&D R&D program is directly linked to EM's cleanup mission priorities at the sites. A structured, rigorous and defensible prioritization process is used to understand the magnitude, technical complexity, and intra- and inter-site linkages of D&D challenges across the DOE complex and to evaluate and rank potential technology projects. D&D R&D program needs, priorities, and technology projects are developed by a technical team consisting of representatives from EM headquarters and field sites (both federal and contractor staff), academia, national laboratories, industry, and international partners. The result of this process is an extensive list of technology needs/gaps and strategic initiatives that provide a target-rich environment for improvements in safety, efficiency and schedule.

A five-step sequential approach is used to identify and evaluate potential technology solutions to address the D&D R&D technology needs identified during the prioritization process:

1. Commercially available technologies are identified and evaluated for applicability to DOE site needs. If the technology has not been used on a DOE site, an evaluation is conducted to assess its maturity and determine if a field demonstration is needed to gain site and regulatory support. If the technology has been used on a DOE site, the D&D R&D program facilitates the exchange of information and lessons learned between the sites and can support field demonstrations.
2. If commercial technologies are available that satisfy some, but not all, of the site D&D requirements, the D&D R&D program supports a re-engineering effort to modify the commercial technology to meet site needs. This is followed by a field demonstration to test the effectiveness of the re-engineered system and to determine if further refinement is needed.
3. Developing or emerging technologies are screened and the most promising are identified for further development or testing. The D&D R&D program works with the developer, the site, and regulators to ensure the new technology incorporates site requirements and gains site and regulatory acceptance. This is usually followed by a small scale and/or field test to demonstrate the effectiveness of the technology and collect sufficient cost, safety, and schedule data.
4. Because many facilities to be decommissioned in the DOE complex are one-of-a-kind and/or unique to DOE with unprecedented scope and complexity, the needed technologies are not yet developed. In this case, the D&D R&D program embarks on a R&D effort to have the technology available when needed for insertion into the D&D operating schedule.
5. In addition to technology development, the D&D R&D program also investigates innovative technical approaches and strategies to resolve D&D problems within the DOE complex. In practice, this commonly amounts to a fundamental change in the approach through re-engineering of the task.

To enable the paradigm shift from D&D as a low-tech or no-tech operation to the utilization of new technologies and approaches, D&D R&D planning is taking a strategic perspective on technology development. This plan addresses the technology needs and research efforts for all initiatives in Table I, and it defines a program charter that is based on collaboration, integration, and leveraging of other resources to ensure success. Implementation of the long-term strategic plan will move the D&D R&D program from a reactive response that performs minimal R&D with limited resources to a mature program with stable funding and clear long-term goals and objectives.

The D&D program enlists resources to adapt strategies and technologies from a wide variety of organizations, as well as initiating its own sponsored research to address issues that are unique to the DOE D&D program. Resources are available from the DOE National Laboratories and operating contractors within and outside of the DOE program that bring unique knowledge of problems and creative solutions. Additional resources are available from Florida International University (a routine contributor to the D&D efforts) and other universities. Likewise, other federal agencies, specifically the Nuclear

Regulatory Commission, the National Institute of Standards and Testing, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, and the Department of Defense, conduct R&D programs that are relevant to known D&D needs. Efforts have been initiated to coordinate with and gain access to resources and information that reside in these and other agencies. It is essential for the cost effective development of required technologies that a variety of development strategies be pursued, ranging from basic R&D to modification and adaptation of existing technologies for D&D needs. A commitment of resources to collaborate with other organizations and identify applicable technologies will minimize development costs and eliminate duplication in R&D efforts.

DEACTIVATION AND DECOMMISSIONING RESEARCH AND DEVELOPMENT

The D&D R&D program supports the identification, development and timely deployment of adaptive and transformational technologies needed for the safe closure of nuclear, radiological and industrial DOE facilities. The R&D program has linked its current and future developmental efforts with the National Research Council's focus areas, as summarized in Table I. Technology alternatives, technical assistance, and applied research activities within the D&D R&D program are selected and prioritized based on the process noted above and on their potential to meet EM's safety and cost goals.

Characterization, Equipment Removal and Dismantlement

Characterization, Equipment Removal and Dismantlement R&D pursues safety improvement and cost and schedule reduction for high-risk D&D activities (i.e., those involving high-level radiation and other hazards such as asbestos and beryllium) that currently use labor intensive methods. Current projects are developing innovative characterization and monitoring methods, and future projects will focus on advanced characterization systems and equipment removal and dismantlement technologies. The R&D efforts in this area also support the development of correct geometry standards for the non-destructive assay of uranium in the process facilities at Portsmouth and site closure technologies with direct ties into other EM R&D areas (e.g., Tank Waste, Cementitious Barriers, and the ASCEM initiative). Table II summarizes the research opportunities identified by the NRC in the 2001 report [1] and opportunities.

Table II. Characterization, Equipment Removal and Dismantlement R&D

R&D Initiatives	R&D Activities
Characterization Technologies	***Development of technologies for detecting and quantifying radiation*** • *New detector materials and device geometries* • *Fiber optic radiation sensors* • *Quantification and configuration of radionuclides in complex geometries* • *Detection, identification and quantification of radionuclides in isolated systems (e.g. pipes, tanks)* • *Luminescent materials for detection of radionuclides on surfaces* • *Biosensors for detection of radionuclides* • *Indicator and surrogate measures of contaminant presence*
	Development of technologies for detecting and quantifying hazardous materials • *Luminescent materials for detection of hazardous materials on surfaces* • *Biosensors for detection of hazardous materials on surfaces* • *Fiber optic methodologies for detection of hazardous materials* • *X-ray fluorescence (XRF)/ x-ray diffraction(XRD) instrumentation*
	Development of technologies for simultaneously detecting and quantifying multiple analytes • *Reverse photo-acoustic spectroscopy* • *Portable XRF units* • *Fiber optic technologies*
	Development of technologies for detecting and quantifying materials in closed systems • *Gas injection methodologies for detection of hold-up and accumulations of contaminants of concern* • *Non-destructive assay systems for external characterization of radionuclide concentrations in pipes and tanks* • *Remote technologies for identification of accumulations and deposits in pipes and tanks (e.g. acoustic, x-ray)*
Equipment Removal and Dismantlement	***Development of remote systems to dismantle, cut, retrieve and package materials*** • *Capability for remote size reduction of equipment* • *Specialty, adaptable tooling for robotic systems* • *Heavy load systems for equipment handlind and removal* • *Laser cutting for removal and size reduction* • *Long reach demolition equipment* • *Underwater robotic platforms with multiple effector capability* • *Cutting tools for use on robotic platforms* • *Smart effectors for packaging waste for disposal*
	Development of technologies for hot cell cleanout using existing access • *Fully remote systems for hot cell characterization* • *Fully remote systems for equipment/material removal* • *Radiation hardened actuators for material handling*

Characterization, Equipment Removal and Dismantlement technology projects being conducted in FY 2011 include:

Hot Cell Characterization with RadBall – The RadBall technology was initially developed by the National Nuclear Laboratory in the United Kingdom and provides an inexpensive technology for obtaining semi-

quantitative and directional information on the extent of gamma contamination. The device is composed of a radiosensitive polymer encased in a tungsten collimator. The device is placed in a contaminated space and left for a predetermined period of time depending on the expected levels of radiation in the area. Following exposure, the irradiated polymer is removed from the device and read using a computerized axial tomography (CAT) scanner. The resulting data is processed to provide a digital 'map' of the distribution of contamination in the space that was measured.

Long Reach Tap Tool - Waste lines, which can read as high as 10 R/hr, contain residual liquid that is difficult to drain and presents a significant worker exposure risk. This project will develop a remote tapping tool that can be operated from a distance when attaching a tap-and-drain assembly to a piping system in high radiation areas. The intent of the design is to modify proven technologies with an "off-the-shelf" hot tapping device for drilling contaminated pipe. The pipe saddle is another commercially-available item; slightly modified to allow for its attachment to the pipe from a distance of five to seven feet. The pipe saddle, hot tap, and drain will all be assembled prior to its installation. A long-handled tool will locate the saddle to the intended pipe and the installation tooling will allow the saddle to be attached to the pipe at distance. The unit will be as lightweight as possible to maximize the chances that it can be operated by a single person without the aid of any lifting machinery. Any drilling, fastening, and actuation required will be done with commercially-available hand-powered tools. The drain valve handle will be opened and closed with a separate and simple long-handled tool. The remote tapping tool will be demonstrated at Idaho in FY 2011.

Personal Protective Equipment and Worker Protection

PPE and Worker Protection R&D will develop and deploy technologies to improve the ability of workers to perform work in hazardous environments. It is beneficial for EM to pursue the development of PPE improvements as most PPE is heavy and bulky, and therefore results in limitation of motion, extra exertion, and overheating of personnel. Improvements in PPE and personnel monitoring—for example, personal heat-stress detectors and technologies to provide real-time information on concentrations of contaminants in the work place—are needed to reduce worker risk and increase productivity. EM is collaborating with the Office of Science's SBIR program, national laboratories, and industry to develop and demonstrate technologies in these areas. Table III summarizes the technical gaps identified in the 2009 NRC report [2] and R&D needs identified by the sites for real-time air monitoring.

Table III. PPE and Worker Protection R&D

R&D Initiatives	R&D Activities
Risk Reduction for Workers	***Heat Stress Monitoring and Management*** • *Light weight, portable personal heat stress monitors* • *Light weight personal cooling apparatus*
	Improved Anti-contamination Suits • *Less cumbersome, but equally protective materials and designs for worker protection suits*
	Real time airborne contamination monitoring • *Real time beryllium monitor* • *Real time asbestos monitor*

PPE and Work Protection technology projects being supported in FY 2011 include:

Collaboration with the private industry will initiate technical exchanges and site demonstrations of commercially-available technologies such as the Personal Heat-Stress Detector System.

The D&D Program is collaborating with the Office of Science Small Business Innovation Research (SBIR) Program in a call for proposals for using nanotechnology to develop the next-generation anti-contamination suits.

Decontamination

Decontamination R&D will improve scientific understanding of the fundamental chemical, biological, and physical interactions between contaminants and buildings/equipment materials to provide significant advances in decontamination methods and technologies. Technologies developed and tested in this R&D area will be designed to decrease worker exposure in hot cells and gloveboxes where radioactive materials are handled and to minimize contact with contaminated materials. This R&D area includes demonstrations of technologies for decontaminating surfaces and equipment contaminated with plutonium and other radioactive isotopes and the passivation of sodium in reactor piping and equipment. Table IV summarizes the research opportunities identified in the 2001 and 2009 NRC reports [1, 2].

Table IV. Decontamination R&D

R&D Initiatives	R&D Activities
Surface Decontamination	***Hot Cell and Glove Box Decontamination*** • *Research toward understanding interactions between construction materials and contaminants* • *Expand capabilities of existing decontamination agents* • *Development of decontamination agents that can 'extract' contaminants from materials pores and cracks* • *Develop bio- and nano-materials for decontamination* • *Materials and equipment for remote application and removal of decontamination agents*
Equipment Cleanout	***Passivation and removal of contaminants*** • *Establish chemical and physical parameters necessary to optimize the passivation of hazardous material holdup in piping and equipment* • *Develop materials and processes for decontamination and removal of internal contamination in equipment* • *Develop materials and processes to passivate hydrogen fluoride and reaction products in piping*

Decontamination technology projects being conducted in FY 2011 include:

Development and Demonstration of DeconGel™ - EM has collaborated with Cellular Bioengineering Inc., in the production and refinement of a decontamination gel (DeconGel™) that is spread or sprayed on the surface and allowed to cure before it is removed as a strippable film. This gel is water based and contains <5% ethanol and other proprietary compounds. The gel was used successfully to decontaminate a plutonium glove box at Lawrence Livermore National Laboratory, a plutonium and americium spill at Oak Ridge National Laboratory, and a shear at the Hanford site. Additional demonstrations are planned at West Valley and other DOE sites in FY2011.

Sodium Passivation - The residual sodium (e.g., remaining on walls and hydraulic low points) in the sodium cooled EBR-II nuclear reactor was passivated using moist CO2. Most of the sodium was successfully treated, however, some of the sodium could not be reached, and in much of the piping, a bicarbonate layer formed which impedes treatment of the underlying sodium. A new method is being

developed and tested to safely but effectively treat the remaining residual sodium in the presence of sodium bicarbonate. Bench-scale tests are being performed to establish the chemistry, flow rates, and temperatures and ranges that are most conducive to safe and effective removal of sodium medal, sodium bicarbonate, and their residues and reaction products. If successful, this technique has potential utility at Hanford and other nuclear sites around the world.

Robotics and Intelligent Systems

Numerous facilities in the DOE complex are unsafe or inaccessible for human entry due to structural instability, high radiation levels, or confined spaces. Opportunities exist to reduce cost and schedule and improve worker safety through the use of robotic and/or teleoperated platforms with smart tooling systems. Robotics and Intelligent Systems R&D will develop next-generation robotic systems that can adapt to a variety of environments and topographies, be semi-autonomous to provide a more intuitive human-robot interface, prevent accidents, and achieve high reliability.

Table V summarizes the research opportunities identified by the NRC in the 2001 report [1] for robotics and intelligent machines. Robotics and intelligent systems is a rapidly expanding area and the D&D program will continue to assess new scientific and engineering developments in this area and the applications to D&D.

Table V. Initiatives for Robotics and Intelligent Systems R&D

R&D Initiatives	R&D Activities
Robotics and Intelligent Systems	***Modular Robotic Platforms for Rapid Deployment of Instruments and Equipment in Hazardous Areas*** • *Disposable' robotics and remote systems for deployment of contaminant characterization instruments* • *Robotic and remote systems platforms for equipment dismantlement and removal*
	Anthropomorphic Hands and Arms for Advanced Teleoperation • *Robotic hand with 'human-like' dexterity and strength based on cost effective and robust mesofluidic actuators* • *Advanced touch and force feedback sensing for human scale hands* • *Mesofluidic human scale arm and master controller*
	Smart Tooling Systems With 'Intelligent' Interfaces • *Articulated sensor-based remote tooling to improve the dexterity of standard remote systems* • *Smart tooling shared control between the remote operator and automated sensor-based tooling*
	Virtual Presence for D&D Inspection and Planning • *Contamination hardening of 3D scanning systems to permit deployment in hazardous environments* • *Scanning algorithms to compensate for containment package distortion* • *Operator interfaces and information representation to permit lifelike visual inspection of hazardous facilities*

The Robotics and Intelligent Systems technology project being conducted in FY 2011 is the Remote Stack Characterization System. This project provides an innovative approach to remotely characterize highly contaminated, structurally deteriorated stacks associated with gaseous waste treatment operations. The project team will complete the detail design and fabrication of a remote stack characterization system in the second quarter of FY 2011. The design utilizes an overhead crane to deploy the system through the

top of the stack. The system periodically stops, unfolds, and stabilizes itself against the inside walls of the stack. Cameras and lighting provide operations and inspection data. Distance down the stack and rotation are provided to correlate data with specific locations within the stack. On board instruments quantify alpha, beta and gamma radiation levels on the inside wall of the stack. An automated smear sampler takes and catalogs an array of samples as directed by the operator. A remote core sampler takes multiple core samples during the same campaign. A field demonstration of the Remote Stack Characterization System is planned for the third quarter of FY 2011.

End States—In situ Decommissioning

In Situ Decommissioning (ISD) is being actively pursued for a few very large and robust facilities in the DOE complex. Generally, ISD involves entombment of contaminated components in grout or concrete, thereby isolating the contaminants from contact with transport mechanisms (e.g. wind and water) that could result in the dispersal of contaminants into the environment. ISD poses novel technical challenges, including permanent isolation of contaminants in the grouted materials and monitoring of the exterior shell of the facility to verify structural integrity. There is a need for novel fill materials that produce less environmental impact than traditional grout/concrete mixtures. Monitoring methods and technologies must be developed to provide continuous and timely information about the integrity of the entombed structure, and methodologies and models are needed to predict the long-term fate of these structures over the centuries required to ensure the isolation of long-lived radionuclides. The End States—In Situ Decommissioning R&D Area addresses those challenges.

Table VI summarizes the research opportunities identified by the NRC in the 2001 report [1] to achieve desired end states and the R&D requirements identified in strategic planning workshops focused specifically on In Situ Decommissioning [3].

Table VI. End States—In Situ Decommissioning R&D

R&D Initiatives	R&D Activities
In Situ Decommissioning--Entombment	***R&D for Specialty Grouts and Alternative Fill Material*** • *Specialized grout formulations with unique flowability and curing properties* • *Specialized grout formulations with non-reactive chemistries* • *Alternative fill materials that meet performance requirements for ISD closures* • *'Green' grout and fill materials for in situ closures* • *Self healing and contaminant binding grout formulations*
	Remote Sensors for Monitoring of Closed structures • *Attached and embedded sensors to detect structural changes* • *Attached and embedded sensors to detect concrete degradation* • *Actuated methodologies and probes to detect structural changes* • *Attached and embedded sensors to detect contaminant movement* • *Attached and embedded sensors to detect moisture changes*
	Long-term Performance Analysis • *Long term degradation of concrete structures* • *Long term chemical changes in concrete in varying climates* • *Long term behavior of contaminated materials in grout* • *Degradation rates of contaminated materials embedded in grout*

End State technology projects being conducted in FY 2011 include:

Low pH Grout for the P Reactor - Development of a low pH grout to inject into the P reactor vessel at the SRS. A low pH grout is needed because the high pH of ordinary Portland cement is predicted to generate excessive hydrogen gas when it is injected into the reactor and reacts with the aluminum components.

Sensors for Structures and Contaminants - Development of a sensor-based, long-term monitoring program for the DOE ISD facilities. Research interest in sensor measurement parameters are tied to two key data needs: verifying structural integrity of the facility and demonstrating immobilization of contaminants. Sensors that monitor for strain and corrosion will provide data for performance models that evaluate the long-term stability of reinforced concrete.

Degradation Rates for Structures - Research on the degradation rates for steel-reinforced concrete is important because all materials used in original construction and closure of ISD facilities will deteriorate over time. The focus of this research is in three areas: physical and chemical characterization of materials, performance testing of the aged materials, and incorporation of field and laboratory degradation rates into a mechanistic long-term performance model.

CONCLUSION

EM's current focus on accelerated footprint reduction of highly contaminated and, in some cases, structurally unsound facilities, presents significant new technological challenges to maintain worker safety and effective project execution. The D&D technology program is poised to make a significant contribution to meeting this challenge through the development and deployment of transformational technologies and new approaches needed to execute the high-cost and high-risk D&D projects. The result of the collaborative effort between headquarters, the field sites, national laboratories, universities, and the private sector has produced an extensive list of technology needs/gaps and strategic initiatives that provide a target-rich environment for improvements in safety and cost and schedule reductions. A strategic long-term plan is being finalized which creates a logical case and vision for federal government investment in technology development and deployment, technical assistance, and applied research.

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