TEN YEARS OF TECHNOLOGY DEVELOPMENT FOR ENVIRONMENTAL REMEDIATION

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ABSTRACT

The Office of Environmental Management (EM) was established in 1989 to provide a single organization within the U.S. Department of Energy (DOE) to address the cold war legacy of environmental contamination. From the beginning, the Office of Science and Technology (OST) was an integral part of EM. OST was tasked with identifying and developing innovative technologies that would help EM meet its cleanup goals and reduce the overall cost of cleanup at DOE sites nationwide. In 1989, there were few cleanup options for radioactive and hazardous waste, existing technologies were time consuming and expensive, and in some cases, there was no solution for containing or removing waste. For example, EM had few effective options for addressing subsurface contaminants in soil or groundwater. Locating contaminants meant drilling many expensive wells. Waste removal involved excavation (with the potential to expose workers and the environment to the contamination), or decades of pump-and-treat operations without assurance of meeting regulatory cleanup requirements. OST was tasked to research, develop, demonstrate, and deploy innovative technologies that solved EM cleanup problems. Technology solutions deployed with OST's support have enabled contamination to be detected, characterized and remediated, waste to be managed, worker safety to be improved, and cleanup to be completed at a number of DOE sites. OST's primary measure of success is the number of technologies deployed; in many cases OST technologies enable significant cost or time savings. While these are quantifiable and easily understood measures of success, OST also provides equally important contributions based on research and development, technical assistance and an improved ability to apply technologies to solve EM cleanup problems.

INTRODUCTION

OST has evolved over the last ten years to respond to its stakeholders and to better serve the needs of its primary customers – the problem owners within EM at DOE sites across the nation. OST's other customers include those affected by and involved in the EM cleanup program, such as regulators, State officials, and citizens. OST's original mission was to carry out an aggressive national program of applied research and development to improve existing technologies and to develop innovative ones. But technologies shouldn't be developed for technologies' sake. They must be linked to specific cleanup needs. And once their viability is demonstrated, new technologies must be accepted by problem owners, approved by local stakeholders, and written into regulatory agreements before they can be used. As EM has moved to link cleanup needs with research and development (R&D) activities, OST has responded by implementing a solutions-oriented approach.

To help innovative technologies transition from R&D to cleanup solutions, OST has established communication channels with its EM customers, regulatory agencies and the public. OST seeks their active participation to encourage acceptance of innovations in remediation technologies and processes. OST has also expanded the use of partnering and interagency agreements to leverage resources and take advantage of discoveries being made in the private sector and overseas.

In 1998, EM line organizations and OST published new research and strategic planning documents that described an operational philosophy and R&D portfolio that was responsive to EM cleanup needs and endorsed by each EM line organization. OST responded by re-emphasizing a Focus Area-centered approach to integrate R&D efforts within EM problem areas and provide a single OST point of contact for cleanup project managers. OST is working with EM line organizations to redefine the role of science and technology to reflect integrated partnerships with problem owners at EM sites. OST has implemented organizational and management changes to help shift its focus to include a broader mission that addresses implementation needs. Through technical assistance and multi-site deployment programs OST has significantly increased the number and quality of innovative technologies being applied to EM problems.

For example, OST Focus Areas are aligned with EM cleanup program needs identified by customers, users, regulators, and stakeholders. OST Focus Area Technical Assistance Teams provide end users with urgent, on-demand consultation in specific problem areas at EM cleanup sites. These teams help end users select potential solutions for their remediation challenges, troubleshoot technology installations, and tailor solutions to specific applications for optimal performance.

Focus Area Steering Committees work in conjunction with the Focus Areas to help guide prioritization and funding of OST programs. These end-user groups include mid- and senior-level operations staff from EM line organizations who act in an advisory role to the Focus Areas to help ensure that OST pursues new science and technology only if the capability to solve an EM problem does not already exist.

Site Technology Coordinating Groups (STCGs) help coordinate the identification of site technology needs with OST activities, and help implement appropriate technology solutions. STCGs serve as the primary interface between the site programs and the focus area teams. They help facilitate communication about technology issues among technology providers, DOE sites, regulators, and stakeholders.

The Innovative Treatment Remediation Demonstration (ITRD) program reduces barriers to technology deployment and helps accelerate the adoption and implementation of new and innovative remediation technologies. ITRD involves government, industry, and regulatory agencies in technology assessment, implementation, and validation.

Accelerated Site Technology Deployment (ASTD) provides incentives for multiple sites to deploy innovative technologies through cost sharing or matching, technical assistance, and focusing on specific site problems. ASTD projects are driven by EM cleanup site managers. By promoting multi-site deployment of innovative technologies and processes, ASTD encourages sites to coordinate efforts and share lessons learned. There have been 139 planned and actual deployments in the program to date (73 technologies at multiple sites in FY1998 and FY1999, 58 in FY2000). In FY2000, the program required participating sites to fund half of the deployment costs, complete projects within two years, and work with other deployments already planned. ASTD anticipates that multiple site deployments will rise dramatically in years to come.

Technology solutions deployed with OST's support have enabled contamination to be detected, characterized, and remediated, waste to be managed, and cleanup to be completed with less risk and reduced hazard to workers. OST continues to increase emphasis on teaming with EM customers to develop and implement technical solutions that are aligned with EM program needs. Today, OST is a customer-driven organization tied to end-users and committed to facilitating the transition of innovative technologies from development to use.

OST Focuses on EM's Highest Priority Problems

With 113 sites, EM manages some of the most technically challenging and complex work of any environmental program in the world. When EM was formed, there were no existing cost effective restoration or waste management solutions for millions of gallons of high-level waste stored in underground storage tanks, subsurface contamination in soils and groundwater, thousands of cubic meters of mixed hazardous and radioactive waste, or thousands of old facilities in need of decontamination and decommissioning (D&D). OST is working to identify and deliver innovative technologies and processes to help solve these problems and to help EM avoid the even higher costs associated with delaying cleanup and adjusting current schedules. OST has enabled cleanup where no solution currently existed, increased worker safety, and reduced the high cost of cleanup. OST has made a major contribution to each of EM's highest-priority problem areas, as shown in the table below.

Table I. OST Solutions for EM's Highest Priority Problems

Problem Area	**OST Solution**	**Deployments**
High-level waste	• robotic arms for waste retrieval, dislodging, and movement • separation systems to remove solids from liquids and to remove Cesium • volume reduction processes to reduce the amount of waste requiring treatment and disposal	More than 30 high-level waste tank remediation technologies demonstrated with over 80 deployments
Subsurface Contamination	• well drilling techniques to assess waste and minimize contamination spread • sampling systems for better characterization • dynamic underground stripping for destroying DNAPLS • barriers to capture and treat contaminants underground • groundwater detoxifiers to immobilize toxins • thermal methods to mobilize and extract chlorinated solvents from the subsurface in months rather than decades • enhanced bioremediation to enable in-situ (in place) destruction of organics at lower cost than conventional ex situ methods	More than 50 technologies demonstrated for subsurface contamination with 150 deployments.
Deactivation and Decommissioning (D&D)	• mapping systems and contamination analyzers to document and assess contamination quickly • underwater measurement systems for characterization • cutting torches, saws and remotely operated systems for rapid, safer facility demolition • cooling suits to enhance worker comfort and safety	More than 75 technologies for deactivation, decommissioning, and dismantlement of facilities with over 150 deployments
Transuranic (TRU) and Mixed Waste	• assaying systems to certify waste drum content for shipment to Waste Isolation Pilot Plant (WIPP) • automated data validation systems • waste immobilizer for small-particle waste • lead and debris stabilizer	New treatment technologies to address more than 90% of EM's mixed, low-level waste.

MEASURING CONTRIBUTION AND SUCCESS

In recent years, EM line organizations have developed performance measures that demonstrated the dependency of each organization on the other to achieve success. For example, EM cleanup sites have developed baseline program costs for project completion as a means of comparison against using new technologies. Today, EM uses life-cycle calculations to account for future cost savings, rather than year-to-year calculations. OST R&D is integrated into EM's life cycle planning.

OST's primary measure of success is the numbers of technologies deployed; in many cases OST has also enabled significant cost or time saving. The number and quality of OST deployments have steadily increased, as shown in the graph below.

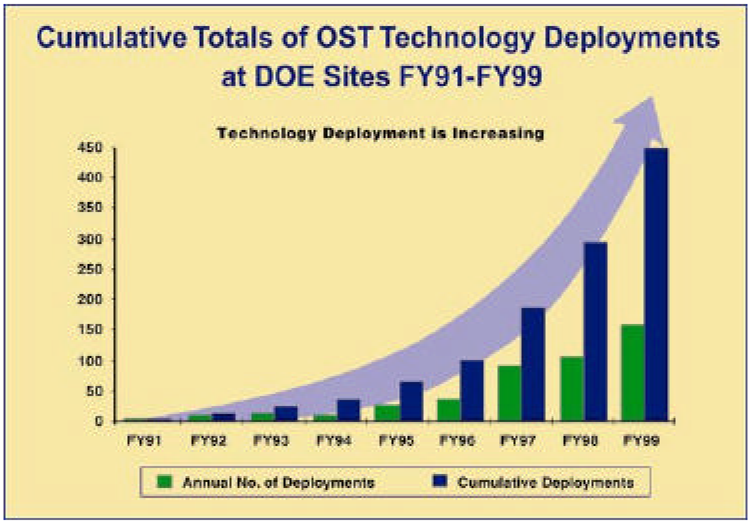

Figure I

Fig. 1. OST Deployments FY91-99

Specific examples include innovative thermal methods to mobilize and extract chlorinated solvents from the subsurface in months rather than decades, and enhanced bioremediation to enable in-situ (in place) destruction of organics at lower cost than conventional ex-situ methods. While deployments are visible and easily understood measures of success, OST also provides equally important contributions based on the impact of R&D and the ability to use technologies to solve problems. Internally, OST has established "stretch" and performance goals to help address EM cleanup needs. OST tracks demonstrations, and at least one Focus Area, Subsurface Contaminants Focus Area (SCFA) has set internal targets for providing at least 100 Technical Assistance Team solutions in the two-year period 2000-2001. SCFA performed 41 technical interventions at EM sites, upon request, in the last year.

EM's stakeholders, including Congress, citizens, regulators, State governments, and Indian Nations want to ensure that cleanup is completed as cost-effectively, safely, and quickly as possible. Of the approximately $57 billion Congress has invested in EM over the last 10 years, about $3 billion (~ 4% of the total) was invested in OST. OST's budget today is about 4% of EM's total current budget of $6 billion. These are large sums of money, and stakeholders want to know what is being delivered from the considerable investment made in the EM cleanup program.

When discussing contribution and success, the natural tendency is to identify compelling examples of cost savings and other metrics such as return on investment (ROI) measures that are effortlessly understood and easily remembered. The typical ROI for private sector R&D organizations ranges from 11 % to 40% [1] depending on cost factors included in the calculation. According to a June 15, 2000 White House report on R&D investments, economists estimate that private rates of return on R&D spending average about 24%. [2]

Cost savings is an essential component of measuring OST and EM success. OST customers and stakeholders have noted that it is important to examine additional measures that address the impact of technology R&D, such as the ability to accomplish a program objective more easily, with less environmental impact, or with less risk. OST has contributed significant cost savings that tend to suggest a high ROI (as identified in later sections of this paper). Today, OST can point to approximately $6 billion in cost savings from deploying specific new technologies. However, for government agencies, calculating standard ROI numbers is challenging. There are other measures that point to OST's contribution.

As of September 1999, OST technologies had recorded 450 deployments at 35 sites (this includes multiple deployments of the same technology; see Figure 1 above). The majority of these deployments took place in the last three years. Nearly 300 individual technologies have been deployed. At the end of 1999, almost 200 of the technologies OST invested in had been used at one or more EM sites, and the majority were commercially available. OST's deployment success rate is about 20%, and increasing—to date, one of every five OST R&D projects has resulted in a viable technology that is being used.

Metrics are essential, but there are other areas of contribution that have a large impact on EM. In the private sector, a new management approach called "technology valuation" is being used to measure the value of R&D contribution. It includes both metrics such as ROI or program output, as well as expected and unexpected accomplishments, such as a user or customer doing something with the new product that achieves a desired or potential benefit. Within EM, OST's contributions include technology deployments and cost savings, as well as less quantifiable results of applying technologies to problem areas. Some examples include:

- increasing the scientific knowledge base, which enables better decisions and prevents dangerous and costly mistakes
- facilitating opportunities to use solutions developed by private sector technology vendors
- developing cooperative relationships with regulators and other stakeholders
- providing expert technical assistance to solve specific problems
- reducing technical risk and increasing worker safety
- incorporating long term stewardship aspects into cleanup solutions
- addressing short-term clean up problems with identified needs and planning for future needs associated with longer-term, extremely challenging problems.

EXAMPLES OF OST's TEN-YEAR CONTRIBUTION TO EM CLEANUP NEEDS

Examining OST's contribution from this broader perspective can help solve the problem of measuring and communicating its value to stakeholders and customers within EM, as well as outside DOE. The rest of this paper will present OST contributions to EM within the context of measures or themes that have both qualitative and quantitative aspects. Each represents a critical area that positively impacts the EM cleanup program. The themes are:

- OST is fully integrated into the cleanup effort.
- OST technologies are helping sites redefine baselines.
- OST technologies and systems are enhancing worker safety.
- OST technologies help sites reduce environmental risk.
- OST technologies and services reduce costs and schedules.
- Basic and applied research brings science to bear on cleanup needs.
- OST works with other agencies to leverage technology investments.

OST IS FULLY INTEGRATED INTO THE CLEANUP EFFORT

OST is customer-driven – OST's customers are EM site problem owners. OST's R&D planning process is anchored in a disciplined, documented method of identifying, prioritizing, and meeting EM cleanup needs. Systems engineering ensures that OST decisions are needs driven, defensible, and cost effective and that they satisfy both stakeholders and regulators. Current EM life-cycle planning data identifies 160 projects with technology needs. In FY 2000, 86% of high-priority site needs, and nearly 90% of all site needs were at least partially addressed by OST Focus Areas' research plans and activities.

Technical Assistance Teams

OST's Focus Areas provide technical assistance for urgent on-site consultation and problem solving. These technical assistance teams help end users select potential solutions for their remediation challenges, troubleshoot technology installations, and tailor solutions to specific applications for optimal performance. These teams are made up of the brightest scientists and engineers from higher education, laboratories, and the private sector. At the Paducah Gaseous Diffusion Plant in Kentucky, a technical assistance team recommended ways to accelerate cleanup of on- and off-site groundwater. The team worked with staff of the Innovative Treatment Remediation Demonstration Program to identify about 30 technologies that could enhance remediation and reduce costs. The team also went to the Pantex site to respond to the discovery of trichloroethylene in the Ogallala Aquifer beneath the plant. The team recommended several groundwater characterization improvements and identified and outlined innovative technologies to remediate and monitor contaminants.

Innovative Treatment Remediation Demonstration (ITRD) Program

OST participates in technology verification and assessment programs that help remove roadblocks to technology commercialization and regulatory acceptance. Programs include third party verification programs, which help increase the credibility of performance data among problem owners and regulators. OST and EM's Office of Environmental Restoration jointly fund the ITRD program to help accelerate the adoption and implementation of new and innovative technologies. It was developed as a Public-Private Partnership program with Clean Sites, Inc., and the Environmental Protection Agency's (EPA's) Technology Innovation Office. The ITRD program attempts to reduce classic barriers to technology deployment through the involvement of government, industry, and regulatory agencies in technology assessment, implementation, and validation. These barriers include regulatory and industry concerns about validated cost and performance data, lack of industry and regulatory familiarity with and involvement in new technology demonstrations, and industry's fear of penalties or increased costs if a new technology fails to precisely meet current cleanup agreements.

An ITRD program at the DOE Pinellas Plant near St. Petersburg, Florida, evaluated technologies to remove contaminants from groundwater. ITRD advisory groups composed of DOE, EPA, industry, and state and federal regulatory representatives worked with Pinellas to review and evaluate applicable innovative remediation technologies to enhance a baseline pump-and-treat-system. Several technologies were identified for possible application and as a result, ground water contamination levels will be reduced to drinking water standards at the site in three to five years, with significant cost savings (approximately $5-10 million).

Compliance Assistance

Innovative technologies reduce technical risk and help sites meet compliance agreements by enabling cleanup that couldn't be done before, reducing budget requirements and accelerating schedules, helping to achieve regulatory compliance, and providing reductions in the cost of achieving or maintaining compliance. OST is involved in helping sites achieve regulatory compliance and helping sites negotiate with regulators to get new technologies accepted. In some cases, technical and regulatory issues remain problematic, and in some cases, EM could miss deadlines if these problems are not resolved. OST has been able to make a significant difference in this area.

To meet waste management goals and reduce risk at sites across the nation, EM needs to ship waste to the Waste Isolation Pilot Plant (WIPP) for disposal. For example, Idaho National Environmental and Engineering Laboratory (INEEL) plans to ship 3,100 cubic meters of contact-handled transuranic waste to WIPP over the next 5 years. There are approximately 20,000 data packages whose contents must be validated before shipment can take place. OST has identified an assay method that uses an expert system for data validation that can have a significant impact. Faster data-package turnaround and reduced staffing requirements may reduce budget requirements for data validation by as much as 60% at INEEL. OST's Standards for Performance Demonstration Program enabled other EM sites (INEEL, Los Alamos National Laboratory, and Rocky Flats) to become certified to ship waste to WIPP.

At the Mound site, an OST technology called SAMMS (self-assembled monolayers on mesoporous supports) is going to be used starting this year to address an oil contaminant that is in the critical path to site closure. Mound will use a combination of SAMMS and other technologies to stabilize mercury-contaminated oil from sumps, vacuum pumps and glove boxes. The oil must be removed and stabilized before the sumps and glove boxes can be decontaminated and decommissioned. As an extension of this effort, OST is collaborating with EPA in developing appropriate regulation for monitoring alternative treatment processes for mixed waste. The standard approach has been for EPA to announce a rule-making effort, obtain technical input largely from one EPA contractor, publish a proposed regulation, revise the proposed regulation in response to public comment, and then promulgate a Final Rule. Regulated entities are not involved until the public comment period, at which point their input is received in an adversarial atmosphere. In this innovative approach major regulated entities such as DOE (through OST) are involved in the initial phases of the formulation of proposed regulation, with opportunity to provide sound technical input well in advance of the adversarial phase of the regulation development.

New Approaches to D&D

At the Hanford site, OST participated in a testing and demonstration project that implemented a new approach to allow a deactivation and decommissioning project to be completed. Nuclear reactors that are no longer being used need to be stabilized in place and monitored to ensure contamination containment. A new approach was used at the C Reactor to reduce the number of surrounding buildings and to entomb the reactor vessel for long-term storage. Over 20 technologies were demonstrated and tested at the C reactor to determine their viability for other D&D projects across the EM complex. As a result of the new approach, the C Reactor was placed in a safe interim storage condition, all outbuildings were removed, the reactor core was sealed, and annual maintenance costs were significantly reduced. Thirteen technologies were deployed and six were recommended for future use; many of these technologies are planned for use at eight additional reactor deactivation projects at Hanford.

At the Argonne National Laboratory – East, OST participated in a large-scale demonstration project (LSDP) at Chicago Pile 5 (CP-5) reactor that received a Hammer Award in 2000 (Vice Presidents Gore's award for reinventing government). The LSDP was a collaborative effort involving DOE, a university, a nuclear utility and three industry members to demonstrate and evaluate performance and cost characteristics of 22 D&D technologies. The LSDP was conducted in conjunction with a successful, nine-year project to D&D the CP-5 reactor. It's benefits included technology integration, establishment of D&D baseline activities to improve safety and decreased cost and production rates.

OST TECHNOLOGIES ARE HELPING SITES REDEFINE BASELINES

As part of efforts to improve EM performance measurement, sites have developed baseline analyses that document existing plans, technologies, and schedules for cleanup. Innovative technologies can be applied to existing EM cleanup projects to improve the baseline with respect to either cost, time, or other measures such as less waste produced during the cleanup process.

In FY2000, over 50 technologies became the new baseline for cleanup projects, in some cases at multiple sites. These included: Resonant Sonic Drilling, Soft-sided Waste Containers, Diamond Saw Cutting, and the Personal Ice Cooling Suit. The Accelerated Site Technology Deployment program has been instrumental in integrating technology solutions with site operations to accelerate schedules, reduce costs, and improve the baseline.

Cleaning up Contaminated Soil and Groundwater

The Segmented Gate System (SGS) uses a computer controlled mechanical sorter to separate suspected radioactive contaminated soil into clean and contaminated waste streams. This is accomplished by passing soil, via a conveyor belt, under two banks of sensors that will detect radionuclide concentrations above the desired limits based on the specific contaminant and regulatory requirements. This soil is then diverted into a separate waste stream for removal.

Dynamic Underground Stripping (DUS) uses steam injection to sweep contaminants from permeable sediments. Condensed steam and mobilized contaminants are then recovered through pumping extraction wells in the center of the plume. Hydrous Pyrolysis/Oxidation is then deployed to destroy residual contamination in-situ by oxidation. The combined processes work much faster than conventional pump-and-treat processing of contaminated groundwater.

Used to access the subsurface for installation of monitoring and/or remediation wells and for collection of subsurface materials for environmental restoration applications, Resonant Sonic Drilling provides excellent quality, relatively undisturbed, continuous core samples for contaminated site characterization and subsurface engineering design. The system employs a combination of mechanically generated vibrations and rotary power to efficiently penetrate the soil. Because it uses no drilling fluids, it minimizes generation of waste associated with the drilling operations. It has been deployed at Hanford, Savannah River, Fernald, and Idaho.

Improving D&D baseline technologies

The Oxy-Gasoline Torch cuts thick metal up to four times faster than oxy-acetylene torches and produces a cleaner cut with less slag generated and no material reconnecting after the pass. It works well on components that have significant quantities of rust on the interior surface. Although it costs about $800 more than an acetylene torch, it requires only about $3 of gasoline to cut the same amount of material that requires a $50 tank of acetylene. It has been used extensively at six sites and has become the baseline for many projects.

D&D debris classified as low-level waste (LLW) is typically loaded into plywood or metal boxes for transport and disposal. The soft-sided “Lift-Liner” containers, made of multiple layers of polypropylene, are compact and light enough to be moved by hand when empty, but they hold up to 260 cubic feet and 24,000 pounds, equal to three metal or four wooden containers. Each container costs about $1,800 less than the rigid alternative, accepts larger pieces of debris, and traps less void space allowing more efficient use of storage space and leaving less chance of future settling in landfills. D&D operations at INEEL are currently using the bags as the waste container of choice for LLW debris. They have also been used at Pantex.

Large radioactive steel structures and highly reinforced concrete walls found in decommissioned research reactors have met their match in diamond wire technology. The Diamond Wire Saw safely and cost- effectively cuts heat exchangers, tanks, and other objects while significantly reducing worker exposure to highly contaminated and radioactive materials. The technology is being used for the Tokomak Fusion Test Reactor (TFTR) in Princeton, New Jersey, and the bioshield and associate structures at Battelle laboratories in Columbus, Ohio.

A small, remotely operated submersible vehicle, known as Remote Underwater Characterization System (RUCS), has been used at INEEL to visually survey the canal connecting two underwater reactors and gather radiological characterization data. Its small size and maneuverability allowed it to closely approach objects and view them from various angles. This technology requires fewer people to be suited up in the canal area than the baseline technology, saving labor costs and reducing the potential for personnel exposure and contamination.

The Surface Contamination Monitor is a motorized characterization and data analysis system for surveying contaminated floor and wall surfaces. It produces timelier, consistent, and reliable contamination maps than baseline methods. The monitor provides real time imagery, delivers results up to 10 times faster than conventional instruments, and automatically generates rigorous documentation reports to meet free-release requirements. At the Nevada Test Site, the system surveyed and documented an area the size of six football fields in days instead of months. It has been deployed at six DOE sites.

In some cases, OST identifies commercial technologies that will enable DOE to meet regulatory compliance criteria much more efficiently than the baseline procedure. For example, OST demonstrated a commercial technology, originally developed for a different use, that become the baseline for lead paint analysis. The Lead Paint Analyzer provides non-invasive, in-situ, real-time analyses of contaminants, reducing costs and schedule for deactivation and decommissioning activities. The unit pays for itself in less than 20 samples. A new project to deploy this technology across multiple sites began in 2000, and OST plans to involve federal and state regulatory agencies to help with technology acceptance.

OST TECHNOLOGIES AND SYSTEMS ARE ENHANCING WORKER SAFETY

One of EM’s six principles is to enhance worker safety. This is particularly important in the deactivation and decommissioning arena. OST technologies enable safer, faster, mo re comfortable and efficient, and more effective cleanup. Intelligent machines work in areas inaccessible to workers to perform in tight spaces with limited access and enable transport and positioning of measuring instruments and retrieval tools. They allo w visualization and characterization of ductwork and piping, and operate underwater or in high radiation areas. Protective clothing and other gear provide safety, comfort and increased productivity by shielding workers from radiation or chemical exposure, reducing heat stress and allowing increased “stay time.” They also help prevent injuries and reduce worker fatigue. Remotely-operated equipment isolates workers from health hazards by reducing or eliminating time spent in hazardous work areas, allowing repetitive tasks to be performed efficiently with minimal worker fatigue, and extending worker’s reach into demolition and remediation areas.

Some examples of OST technologies that increase worker safety and productivity include automated waste sorting and characterization (HANDS-55); remote systems for dismantlement of glove boxes; remotely operated radioassay systems for validating waste types before shipment; and a room fogging tool (Master Lee Insta Cote) that drastically reduces contamination levels.

Cleaning out High-Level Waste Tanks

OST supported the development of several technologies used in an integrated retrieval system for the cleanup of the gunite tanks at Oak Ridge National Laboratory. These included the Houdini Remotely Operated Vehicle and Modified Light Duty Utility Arm. Houdini is a remotely controlled, hydraulically powered, folding vehicle that can pass through 24-inch openings in tanks called risers and then open to a 4 x 5 foot mini-bulldozer, complete with a plow blade. It includes a dexterous, high-payload manipulator; and remote camera system. The Modified Light-Duty Utility Arm is a large, robotic tool that can deploy a 200-pound payload through risers as small as 12 inches in diameter. The MLDUA can be equipped with tools that increase functionality, such as the Confined Sluicing End-Effector. The MLDUA is equipped with two cameras located at the mast and arm junction and an additional camera in the gripper, enabling workers to observe and evaluate the contents and conditions inside high-level waste tanks.

Enhancing Worker Safety

A self-contained core body temperature control system enables workers wearing personal protective equipment in hot environments to keep cool without inhibiting their ability to do various types of work. Personal Ice Cooling System (PICS) is an undergarment like suit made of a nonflammable material. An umbilical cord connects tubing sewn into the material to a 2-liter bottle of frozen tap water stored in an insulated backpack. A three-speed, battery-powered pump circulates ice water through the tubing. Water bottles can be easily removed from the backpack and exchanged as needed, and the only supporting equipment needed is a freezer and temporary cold storage for replacement bottles. The suit improves worker safety, comfort, mobility, and productivity. This technology was developed in the commercial sector (in Canada), and has been deployed at 15 EM sites though OST support.

The Remote Concrete Demolition System (BROKK BM 150) accomplishes concrete demolition tasks in days instead of months and minimizes worker exposure to contaminants and industrial hazards. The machine has been deployed at Argonne National Laboratory and the Idaho National Environmental Engineering Laboratory. With the development of a remote viewing system and strategically placed cameras, operators no longer have to be in the line-of sight. The Compact Remote Operator Console is now being used at Oak Ridge National Laboratory to control other robots used in cutting and removal of overhead piping.

OST TECHNOLOGIES HELP SITES REDUCE ENVIRONMENTAL RISK

OST helps EM contribute to meeting another of its principles, to reduce environmental risk. OST technologies allow remote characterization, in-situ treatment, and isolation of wastes from the biosphere. New characterization tools are faster and generate less waste. They produce timelier, consistent, and reliable contamination data, deliver results in seconds instead of months, enabling immediate remediation decisions. The also eliminate sample-handling errors and wait time for analysis from laboratories, and take accurate measurements at the source without spreading the contamination. Containment systems help minimize treatment areas, prevent the spread of contamination while remediation technologies are developed, and are less costly than excavation and disposal. In-situ treatment limits exposure of hazardous materials to workers and the environment. They further reduce costs and risk by capturing and treating contamination underground, protecting surrounding areas and generating less waste material. New certification and stabilization methods isolate wastes for safe disposal. They help to ensure that materials are properly characterized for waste disposal requirements, provide faster turnaround and cut staffing requirements, isolate wastes from the environment, and produce waste forms that don't deteriorate over time.

Improving Characterization

Waste Inspection Tomography (WIT) is a noninvasive characterization system that helps workers avoid the risk of opening waste packages and taking samples of contents. The mobility of the system contributes to safety. Roughly 90 percent of DOE's transuranic drums are at 10 major DOE sites, while roughly 10 percent are scattered throughout the complex at 40 other sites. By bringing the characterization technology to the waste, the risk of transporting TRU waste drums to characterization facilities is avoided. Drums will be transported only one time to WIPP for permanent disposal.

The Adaptive Sampling and Analysis Programs use an approach that makes use of real-time data collection techniques and in-field decision-making methodologies to guide the progress of data collection activities. The advantages include reduced analytical costs per sample, a reduction in the number of samples and data collected, and a better characterization survey.

Immobilizing Contaminants in Groundwater

A Frozen Soil Barrier is being used at Oak Ridge National Laboratory as an interim measure to contain Strontium 90 and Cesium137 found at the bottom of a disposal pond. The containment is designed to keep ground water from mobilizing the contaminants, until a permanent disposal resolution is taken. The Frozen Soil Barrier is an in-situ containment technology that can be rapidly installed and removed. It minimizes secondary waste, excavation, dust generation, and worker health risk. Injecting water into the breached area can easily repair breaches in the barrier. It uses a benign material (water) as the containment medium. For high-mobility contaminants such as tritium, it may provide the only practical containment measure.

Permeable reactive treatment walls are used to treat/degrade chemicals in groundwater in-situ. A permeable, subsurface barrier containing a reactive material (such as granular iron) is constructed across the path of a contaminant plume. When groundwater passes through the reactive barrier, contaminants are either immobilized or chemically transformed to a more desirable state (e.g., less toxic or more readily biodegradable). EPA reports that 35 passive reactive barrier (PRB) systems have been deployed across the country, using zero-valent iron or other reactive material such as granulated carbon. Some experts estimate that more than 500 sites in the United States may be suitable for PRB deployment over the next 10 years. Compared to pump and treat, PRBs could save more than $1 billion per site over a long-term operation.

Treating Mixed Waste

Macroencapsulation involves heating and pouring low-density polyethylene into a specially designed container partially filled with pieces of a solid, contaminated waste such as lead or debris. The plastic flows around, over, and between pieces of waste, coating and bonding to all surfaces of the waste matrix. The process enables greater waste loading in each container, reducing handling, transporting, and disposal costs. It has been used for disposal of radioactive lead from numerous DOE sites.

OST TECHNOLOGIES AND SERVICES REDUCE COSTS AND SCHEDULES

Achieving EM's cleanup goals will be difficult because of technological and regulatory challenges, and because current methods are costly and time consuming. OST is helping find solutions that accelerate cleanup or simply enable it. This helps EM keep costs down by avoiding costs associated with schedule delays. The seventeen major sites still requiring cleanup beyond 2006 include some of EM's toughest problems – these are problems with no currently available solution. Within EM, there is a widely recognized need for continued investment in science and technology that is integrated with currently identified and upcoming cleanup challenges. The life cycle cost of cleanup work remaining is about $180 billion, and includes four of DOE's most complex sites: Savannah River Site in South Carolina; Oak Ridge Reservation in Tennessee; Hanford Site in Washington state; and the Idaho National Engineering and Environmental Laboratory. OST's Focus Areas will target 80% of these cleanup costs, with almost half devoted to high-level waste.

The table below identifies areas of significant cost savings and cost avoidance that are anticipated at DOE sites nationwide as a result of applying OST technologies to EM cleanup problems.

Table II. Cost Savings Associated with OST Technologies

Problem Area	Cost savings *
High-level waste retrieval, treatment, and disposal and storage tank closure	Enhanced Sludge Washing - $5 billion cost avoidance
	Gunite Tanks Remediation– $350 million cost avoidance and 10 year reduction in baseline project schedule
	Cesium Removal System - $40 million cost avoidance
Identification, containment and remediation of subsurface contaminants	Passive Reactive Barriers - $100 million cost savings at Rocky Flats Environmental Technology Site and Monticello Uranium Mill Tailing Site
	Permeable Reactive Barrier - replaces the older pump-and-treat method and is forecasted to save over $200 million at three EM sites
	Segmented Gate System – projected to save $45 million over baseline
	$150 million reduction in the cost of the cleanup at Fernald using a ground-water injection system and accelerating the schedule by 17 years
	DNAPL Mobilization and Destruction - $20 million cost savings
Deactivation and decommissioning of contaminated facilities	Strippable Coatings for Deactivation - $10 million cost savings at the Savannah River Site
	$500 million savings in the cost of deactivating and decommissioning reactors at Hanford

** Note: Cost savings and cost avoidance numbers are estimates.*

High Level Waste

Enhanced Sludge Washing uses caustic leaching and chromium oxidation to remove non-radioactive chemicals from the sludge. By removing inert chemicals such as aluminum, chromium, phosphorous and sulfate from sludge, higher loadings of radioactive components can be achieved in high level waste glass, reducing by 60% the volume of tank sludges requiring vitrification and repository disposal. Almost $5 billion in cost avoidance is included in the Hanford baseline from this technology.

The Gunite Tanks Remediation project was a "first of its kind" project to remove radioactive sludge from a series of underground waste storage tanks at the Oak Ridge National Laboratory. Robotic and remotely operated equipment was used to clean the tanks and transfer the low-level liquid waste to new stainless steel storage tanks. A total of 30 technologies were used in the project leading to a cost avoidance of $120 million and accelerating the tank cleanup by more than 10 years.

Cesium Removal using Crystalline Silicotitanate and Out of Tank Evaporator technologies greatly reduces low-activity waste handling and disposal costs and avoids major design and operations costs associated with previous methods. The potential complex-wide cost avoidance is in the hundreds of millions of dollars.

Subsurface Contaminants

Passive Reactive Barriers (PRBs) are permeable reactive treatment walls used to treat/degrade chemicals in groundwater in-situ. A permeable, subsurface barrier containing a reactive material (such as granular iron) is constructed across the path of a contaminant plume. When groundwater passes through the reactive barrier, contaminants are either immobilized or chemically transformed to a more desirable state (e.g., less toxic or more readily biodegradable). Compared to pump and treat, PRBs could save more than $1 billion per site over the long-term.

The Segmented Gate System is a very cost-effective approach to soil remediation that removes a minimum amount of clean soil with the radioactive particles, reducing the overall amount of material that requires disposal. Automation not only reduces exposure and speeds the process, it provides a much higher degree of precision and accuracy. All of the soil is analyzed, not just sampled, and the level of radioactivity is documented in both the contaminated and clean streams. It is projected to save $45 million over baseline technologies.

D&D

ALARA 1146 Strippable Coating applies a plastic membrane or polymer on the contaminated surface. The strippable coating is allowed to cure for up to 24 hours, after which it can be easily peeled or stripped off the surface. The coating traps the contaminants in the polymer matrix. Strippable coatings are non-toxic and do not contain volatile compounds or heavy metals. Since the coating constitutes a solid waste, disposal is easier than treating contaminated liquid wastes. Estimated cost savings at the Savannah River Site alone is $10 million.

High explosives in soils pose hazards at some sites and require careful handling. The High Explosive Composting (HE Composting) technology uses the basic principles of composting to achieve degradation of the complex organic molecules that comprise high explosives. Cow manure and wood chips are added to the soil to promote the degradation of high explosives by enhancing the biological growth of cycles of microbes indigenous to the soil. Optimization testing resulted in the recipe for the most effective mix of amendments needed to achieve reduction of the high explosives to levels acceptable for onsite disposal in the shortest possible time. Another cost saving method used was to wet the compost piles with effluent treated at drinking water standards; this avoided the cost of reinjection of this liquid stream. Based on the results of the testing, 90 percent reduction of the starting mass of high explosives is achievable within 15 days. LANL is undergoing bench studies now to determine what composting mix works best at their selected site, the 260 Outfall. The use of composting at the Pantex Plant will save an estimated $2 million in lifecycle costs over the baseline, and received the National Pollution Prevention Award for Environmental Restoration from the Secretary of Energy.

BASIC AND APPLIED RESEARCH BRINGS SCIENCE TO BEAR ON CLEANUP NEEDS

OST invests in basic science research to generate breakthrough innovations and uncover new ideas that lead to the cleanup solutions of the future. OST works with more than 88 universities, 34 national laboratories and governmental and private sector facilities in 39 states and the District of Columbia, as well as seven countries, including Ireland, Switzerland, Canada, Czech Republic, Russia, Australia, and the United Kingdom. With 316 science projects, OST is expanding knowledge in hydrogeology, separations and actinide chemistry, biogeochemistry, geophysics, microbial and plant science, instrumentation, engineering science, materials science, and other core sciences. Grants to universities and labs lead to better understanding of core environmental sciences. EMSP links scientists to problem holders through workshops and by helping solve specific deployment problems.

Basic science research is needed to help solve significant problems that cannot be addressed effectively with current technologies. There are specific areas of research where the Environmental Management Science Program (EMSP) can make significant contributions to solving these problems and adding to scientific knowledge generally. These include the following:

- Long-term issues related to tank closure and characterization of surrounding areas,
- High-efficiency, high-throughput separation methods that would reduce high-level waste program costs over the next few decades,
- Robust, high loading, immobilization methods and materials that could provide enhancements or alternatives to current immobilization strategies, and
- Innovative methods to achieve real-time, and, when practical, in-situ characterization data for HLW and process streams that would be useful for all phases of the waste management program.

EMSP also contributes specifically to EM's principles. For example, EMSP researchers developed personal and environmental exposure assessment measurement tools to help individual workers monitor their exposure in the field. Research into multi-level sampling provides an understanding of the chemical and microbiological conditions at specific vertical locations in the subsurface. And microcantilever sensors provided the basis for real-time, portable, low-cost sensors for remediation and characterization.

Like OST's Technical Assistance Teams, EMSP also gets involved in helping solve specific problems. EMSP helped contribute to solving a problem at the Savannah River Site that directly saved millions of dollars of downtime recovery costs. The Defense Waste Processing Facility, designed to solidify high-level radioactive waste in molten glass, was experiencing problems with a pour spout that were slowing down processing time. The molten glass is poured from the melter into a canister; during pouring, some leakage occurred. The pouring problem was roughly similar to what happens when you try to pour liquid very slowly out of the side of a coffee cup – some of it runs down the side of the cup. Through the EMSP program a number of organizations helped optimize the short-term pour spout insert design solution to correct this pouring problem. The team included plant engineers, the Savannah River Technology Center, OST's Tanks Focus Area, Florida International University, and later Clemson University. The teams developed a "sacrificial spout insert" to regulate the flow as a short-term solution. The work by the universities, and the lessons learned from various design concepts are being incorporated into the design of the next facility.

At EMSP national workshops, scientists and DOE site representatives explore ways to effectively match cleanup needs with relevant research. Researchers present results of EMSP-funded projects in poster sessions and discuss high-priority cleanup needs with end users in breakout sessions. Participants examine ways to bring science into the cleanup decision-making process to better inform stakeholders and policy makers of scientific issues. Principal investigators are encouraged to get involved in the problem definition process and, where appropriate, find ways to rapidly advance projects beyond basic research. Scientists seek better access to samples taken from site problem areas and help in identifying the potential usage of the results at the outset of the research.

OST WORKS WITH OTHER AGENCIES TO LEVERAGE TECHNOLOGY INVESTMENTS

Through partnerships with other agencies, OST provides forums for sharing information on remediation technologies. These forums reduce costs by combining resources and expertise of multiple agencies, and accelerate the adoption and implementation of innovative approaches through cooperation and information sharing. Through partnerships with other countries, OST is working to bring the best scientific expertise in the world to bear on EM cleanup problems. These partnerships encourage US participation in the global environmental market. Partnerships with industry identify commercially available products ready for use at DOE sites, and help accelerate research and evaluation to bring new technologies to the market.

Interstate Technology & Regulatory Cooperation Working Group

The ITRC Work Group, led by state regulators, is developing interstate guidance documents and training programs that are furthering regulatory acceptance of innovative solutions. ITRC provides a forum for state regulators to collaborate with representatives from federal agencies, industry, and stakeholder groups to inform environmental decision makers about the benefits of deploying new technologies. OST participates in and supports this state and federal partnership for streamlining the regulatory approval process. OST works with ITRC to increase the DOE multi-site deployment success rate. ITRC publishes guidelines to help standardize the processes state regulatory agencies use in approving new technologies because uniform guidelines enable faster deployments in a broader range of states.

For example, ITRC played a major role in getting Permeable Reactive Barriers approved at Rocky Flats. In 1997, ITRC had developed a regulatory guidance document for permeable reactive barriers (PRBs) designed to treat chlorinated solvents. Rocky Flats was faced with several technology solutions with widely different costs. Rocky Flats designed and installed the first PRB at a DOE site, and the Colorado Department of Health and Environment reviewed and approved the installation while simultaneously reviewing the draft ITRC document. Having the guidance document improved the efficiency and completeness of the regulatory review. Based on the success of this initial effort, additional PRBs were installed at the site. The guidance document enabled Rocky Flats to implement an innovative technology and replicate its success, thereby saving $2.2–2.7 million in comparison to the baseline solution. The most significant benefit for Colorado and DOE is that the ITRC guidance document contributed to the state's ability to confidently approve the use of this innovative technology, resulting in significant cost savings to tax payers. This technology application has in turn made it easier for other states to consider using the technology

Federal Remediation Technology Roundtable

OST collaborates with other federal agencies through the Federal Remediation Technology Roundtable. The Roundtable is a forum chaired by EPA's Technology Innovation Office for discussing common issues on a multi-agency basis. The work group focuses on sharing information on remediation technology among the federal agencies in the form of case studies, screening matrices and other tools, and demonstrations. Results include multiyear, cooperative projects to demonstrate site characterization and subsurface remediation (DNAPL) technologies.

Interagency DNAPL Consortium

Successful demonstrations of the Roundtable led to the formation of the Interagency DNAPL Consortium, a commitment among DOE, EPA, the Air Force, and NASA to share resources to address subsurface contaminant issues associated with DNAPLS. The Consortium is cooperatively testing and documenting the cost and performance of three innovative technologies for treating dense, nonaqueous-phase liquids, or DNAPLs—compounds that have traditionally proven difficult to characterize and remediate. The Consortium allows OST to focus on technology development, while its partners focus on demonstration and validation information needed by sites, regulators, and stakeholders. DOE is providing financial and research support for the three tested technologies; the Air Force is conducting monitoring and performance evaluation; EPA is providing the quality assurance/quality control function; and NASA is providing the demonstration site.

International Programs

OST international programs emphasize technology information sharing. For example, in collaboration with Russian scientists at the, Khlopin Radium Institute and the Mining Chemical Combine, OST is exploring the use of an ultraporous, inorganic matrix made from coal power plant fly ash to stabilize radioactive solutions. A porous, crystalline sponge, nicknamed "GUPKA," is being studied for use in absorbing plutonium, americium, curium, and Cesium, Strontium and other fission products from waste solutions at moderate temperatures. The trapped isotopes can be recovered by dissolution in acid. Technology demonstrations have been conducted in both the U.S. and Russia. The project is designed to leverage Russian expertise and technologies to develop new technical solutions for Plutonium residue and radioactive waste problems.

More recently, OST reported the first deployment of a Russian-developed technology at Oak Ridge. The Russian Pulsating Mixer Pump is being used to pump out sludge from a high-level waste tank. As a result, closure activities for the tank can begin in the near future.

Industry Partnerships

Many businesses, in partnership with DOE, have developed and demonstrated improved technologies that address environmental cleanup needs. OST support helps many companies conduct applied research, development, demonstration, testing, and evaluation, enabling them to achieve earlier market entry than would be possible under exclusively company-funded development. In turn, as these technologies become available, many are now being deployed at multiple DOE sites to lower costs, reduce health and safety risks, and solve intractable problems.

Regional Technology Deployment Workshops

Over a two year period from 1998-1999, OST hosted technology deployment workshops at three EM sites to bring together problem owners, regulators, public and tribal stakeholders, technology vendors and other officials to identify barriers to technology deployment and discuss methods for breaking down those barriers. Held in Oak Ridge, Richland, and Albuquerque, the workshops were designed to foster relationships, provide needed training, and expedite deployment of innovative technologies. Key themes emerging from the workshops included: exploring new opportunities for financial, contracting, regulatory, communications and management incentives; regulatory flexibility and contract reform; and technical assistance.

CONCLUSION

In its first decade, OST responded to EM problems and needs with demonstrations and deployments of innovative technologies. In the future, OST will continue to manage an integrated R&D program that addresses EM's technology needs and is fully integrated organizationally. OST is working to substantially improve EM's R&D portfolio, better align technology investment with public policy and create a balance between immediate and long-term EM needs.

In December 2000, Assistant Secretary Dr. Carolyn Huntoon told the National Research Council's Board on Radioactive Waste Management that EM still faces significant technological challenges in the next 10-15 years. Difficult issues remain such as groundwater, vadose zone contamination, and long-term stewardship. The influx of facilities from Defense Programs and Nuclear Energy will also pose big challenges, she said. [4]

OST has invested in approximately 950 new technologies to date; 180 are in active development based on the anticipated solutions they will provide. The majority of these technologies are linked directly to an identified EM cleanup need or set of needs at EM sites. Life-cycle planning data indicate 94 existing cleanup projects with high-priority science and technology needs. Estimates for the remaining cleanup and stewardship activities through the year 2070 range from $150 to $200 billion. Recent reports by the National Academy of Sciences have highlighted the need for continued investments in science and technology to accomplish cleanup.

OST's future areas of investment include the following EM high priority needs:

- High-Level Waste—waste characterization and treatment, tank integrity verification, and tank closures
- Subsurface Contamination—waste stabilization and destruction at greater depth and complex geologic structures
- Deactivation and Decommissioning—facilities with higher radiation, thicker concrete, and high-explosive contamination
- Transuranic (TRU) and Mixed Waste—large equipment and packages and remote-handled wastes with high radiation fields
- Nuclear Materials—surplus spent fuel and other nuclear materials
- Long-Term Stewardship—durability of materials, waste containers, and long-term barriers for contaminants remaining at sites; monitoring and surveillance methods; information management; and facility design that incorporates deactivation and decommissioning and waste management

Through continued investment, advances will occur with new or improved technologies to complete the cleanup program and effectively manage long-term stewardship. After cleanup is completed, contamination will still remain at many EM sites. At least 72 of EM's 113 sites, each with widely differing waste types and containment methods, will need stewardship beyond 2070. The Long-Term Stewardship program will establish surveillance, security, and maintenance plans for EM sites and will monitor how new technology developments can improve cleanup and waste management in the future.

OST remains focused on providing EM with science and technical solutions to accomplish its cleanup and stewardship mission. EM annual life cycle costs estimates have risen in the last three years and are expected to continue increasing as we gain understanding and uncover new issues. Estimates of cumulative EM life cycle cleanup costs show that science and technology investments are needed to contain the cost of achieving EM's cleanup goals. To respond to EM's needs, OST is shifting its focus to the most difficult problems, including high-level waste, spent fuel and other nuclear fuel, long-term stewardship, deactivation and decommissioning, and transuranic and mixed waste. One of OST's highest-priorities will remain identifying innovative technologies that enable cleanup that couldn't be done before. Cooperative actions are also needed to continue to encourage private sector partnerships, resource leveraging, stakeholder involvement, and performance measurement. OST will continue to work toward solving EM's toughest problems, while reducing the cost and time of the cleanup program.

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