OVERVIEW OF THE DOE'S PROGRAM TO DEVELOP SAFER, MORE EFFICIENT, AND LESS COSTLY CONTAMINANT SENSORS AND ENVIRONMENTAL AND PROCESS MONITORS FOR REMEDIATING NUCLEAR WEAPONS PRODUCTION SITES AND FACILITIES.

The Characterization, Monitoring, and Sensor Technology Crosscutting Program

This article on the U.S. Department of Energy's Characterization, Monitoring, and Sensor Technology Crosscutting Program is the fifth in an occasional series on the DOE's various focus areas and crosscutting programs. Focus areas already profiled include the Tanks Focus Area, the Subsurface Contaminants Focus Area, the Transuranics and Mixed Waste Focus Area, and the Deactivation and Decommissioning Focus Area. The DOE also has a Nuclear Materials Focus Area. The two other crosscutting programs are the Efficient Separations and Processing Crosscutting Program and the Robotics Crosscutting Program.

By Jerry J. Lorenz

In November 1989, former Energy Secretary James D. Watkins established the U.S. Department of Energy Office of Environmental Restoration and Waste Management (ERWM) and Office of Technology Development (OTD), adopting an ambitious goal to clean up 80 percent of DOE nuclear sites by 2006, with the more challenging sites completed by 2030 (Ref. 1). ERWM quickly realized that achieving this goal in a cost-effective manner requires the development and implementation of safer and more efficient technologies for site characterization and remediation, facility deactivation and decommissioning, and waste treatment and disposal. These paired objectives are the essence of cleaning up and restoring DOE sites throughout the United States for subsequent use and development. To accomplish these objectives, ERWM created the Characterization, Monitoring, and Sensor Technology Crosscutting Program (CMST-CP) to be the focal point and integrator of environmental characterization and contaminant measurement technology development efforts.

Environmental CMST Development[2]

To achieve its environmental cleanup objectives, ERWM first needed to characterize the waste inventory that had been accumulating for more than 40 years at DOE sites, including thousands of contaminated facilities, contaminated equipment, soil contaminated by spills and leaks, waste disposal sites, and contaminant migration in the subsurface. Many of the environmental remediation technologies available in 1990 were inadequate or not economically feasible to use at DOE sites. New technologies and strategies were needed to deal with the diverse assortment of contaminated sites, with their unique combinations and levels of toxic and radioactive contaminants. In addition, the DOE needed a team approach that transcended organizational boundaries to evaluate and coordinate the development of technologies and methodologies to efficiently and cost-effectively achieve its objectives.

SITE CHARACTERIZATION AND REMEDIATION

The first set of cleanup objectives is to characterize contaminated sites in sufficient detail to make possible efficient, reliable, and defensible remediation. To achieve these objectives in a timely manner, the DOE needs faster, less costly, and less environmentally intrusive methods for characterizing subsurface contamination and its potential for moving within the subsurface environment. The DOE also needs technologies to monitor remedial processes in real time as well as to measure the effectiveness of remediation. In cases where complete remediation and restoration are not viable options, the DOE needs technology solutions to contain or immobilize (stabilize) contaminants and to monitor the long-term effectiveness of those solutions.

Conventional remediation technologies were not designed to safely retrieve and treat extremely corrosive and/or highly radioactive wastes stored in surface and underground tanks or in waste lagoons nor to recover buried wastes (some of which are explosive, ignite spontaneously, and/or contain high levels of radioactivity, heavy metals, and hazardous organic solvents). In other instances, where large volumes of soil contain unacceptable levels of radionuclides, heavy metals, or hazardous organic compounds, conventional technologies that rely on excavation, treatment, and redisposal clearly are neither cost-effective nor environmentally acceptable and expose workers to health and safety hazards. Significant technological advances in remediating groundwater are also necessary, especially for situations involving dense nonaqueous phase liquids and for nitrates in deep aquifers. Advances in both initial and final characterization and in situ real-time remediation process monitoring are needed to facilitate the more sophisticated remediation programs that will make these objectives achievable.

FACILITY DEACTIVATION AND DECOMMISSIONING

The second set of cleanup objectives is to close down, dismantle, decontaminate, and dispose of excess DOE facilities and their contents to make decommissioning possible. Technology development is needed to ensure that the deactivation and decommissioning processes used at DOE sites are cost-effective and that they meet all health, safety, and environmental regulations. Since many previously developed decontamination processes are expensive, create excessive waste, and require modifications to satisfy existing regulations, innovative technologies and approaches are needed to meet requirements and to conserve resources.

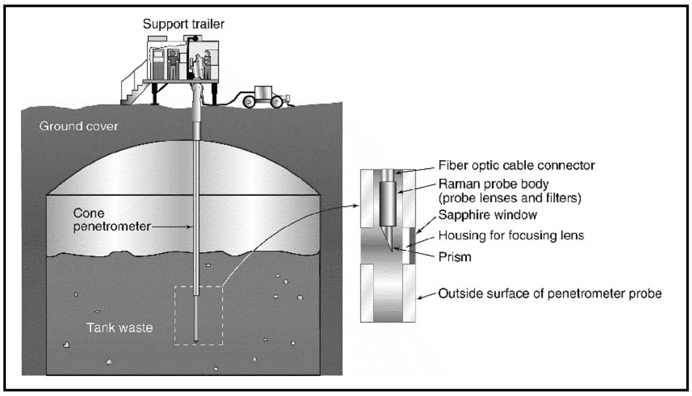
The DOE facilities that need to be decontaminated, dismantled, and disposed of range from underground storage tanks and hot cells to mammoth uranium enrichment and plutonium processing plants. Each facility has radioactive contaminants and, in some instances, toxic substances contained in or on equipment that is difficult to remove because of its unique and complex design. DOE facilities slated for deactivation and decommissioning also include uranium enrichment and fabrication facilities, nuclear production reactors, and fuel reprocessing plants that have massive contaminated structures. Innovative technologies and approaches are needed to safely survey and distinguish the various contaminants on the surface and within equipment, pipes, and other facility materials; these technologies are needed to reduce worker exposure and minimize waste. Each of these activities requires characterization and monitoring to ensure thorough and efficient deactivation and decommissioning meeting with end-user and regulatory approval.

WASTE TREATMENT AND DISPOSAL

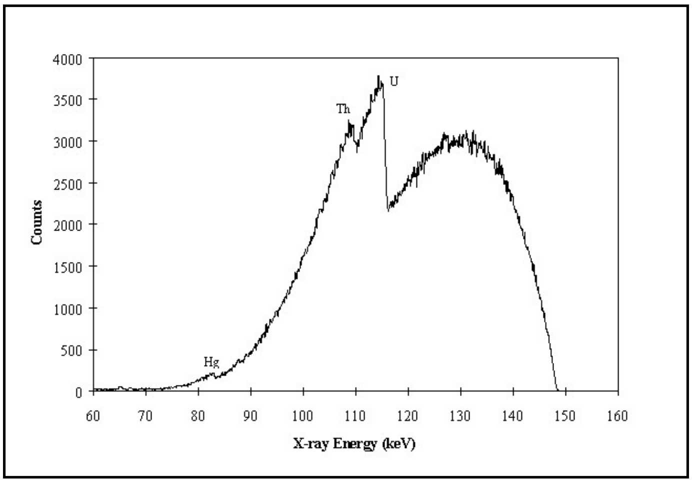
The third set of cleanup objectives is to treat, minimize, and dispose of contaminated materials and to recycle clean materials.

The scope of CMST-CP technical support and expertise encompasses the broad spectrum of chemical and physical measurement and analysis technologies and their implementation.

▲ *Fig. 1. A Cone Penetrometer Truck is shown being used to push a Spectral Gamma Probe into the subsurface. The probe sensor is a scintillation crystal that can identify gamma emitters. The Spectral Gamma Probe is linked to a data acquisition and analysis system that yields real-time results. This technology solution greatly reduces the need to take subsurface soil and groundwater samples for offsite analysis, thereby reducing sampling and analysis costs and at the same time allowing site characterization to be done faster. (TechID 237, 243, 2364)*



▲ *Fig. 2. Illustration of a Raman Corrosion Species Monitor being lowered into an underground waste tank using cone penetrometer technology. This fiber-optic monitoring system uses a laser light-scattering technique to identify and measure chemical compounds. Its use minimizes the possibility of worker exposure to the tank waste and virtually eliminates the need for costly conventional sampling and analysis. A major application is in ensuring chemical conditions conducive to maintaining tank integrity. (TechID 1544)*



▲ *Fig. 3. A chart of the X-ray, K-edge energy spectrum of mercury, thorium, and uranium contamination taken inside a drainpipe. The Portable X-Ray, K-Edge Heavy Metal Detector makes possible the detection of radionuclides within pipes and equipment without having to cut into them. This assay system improves worker safety by revealing internal contamination and locating the best areas to dismantle pipes and equipment. (TechID 134)*

In the process of remediating a site, contaminated soil and substances, including groundwater, are separated from clean soil and groundwater; the clean soil and groundwater are recycled. The extracted waste and contaminated solids are typically packaged in steel drums and deposited in a radioactive waste facility. Nondestructive assay technologies are needed to confirm that the contents of the drums conform to landfill disposal or other storage requirements and regulations prior to delivery and burial.

Specially designed technologies are needed for characterizing, removing, and treating the contents of underground storage tanks and wastewater lagoons. Waste tanks and lagoons often contain significant quantities of highly radioactive wastes mixed with heavy metals, corrosive chemicals, and/or hazardous organic compounds that make personnel entry unacceptable. Specially designed technologies are also needed to characterize and handle contaminated wastes and nuclear materials such as spent reactor fuel. Remotely operated instrumentation and analysis systems are needed to reduce radiological exposure to workers and to monitor waste extraction conduits, such as pipelines, and treatment processes, such as vitrification and stabilization.

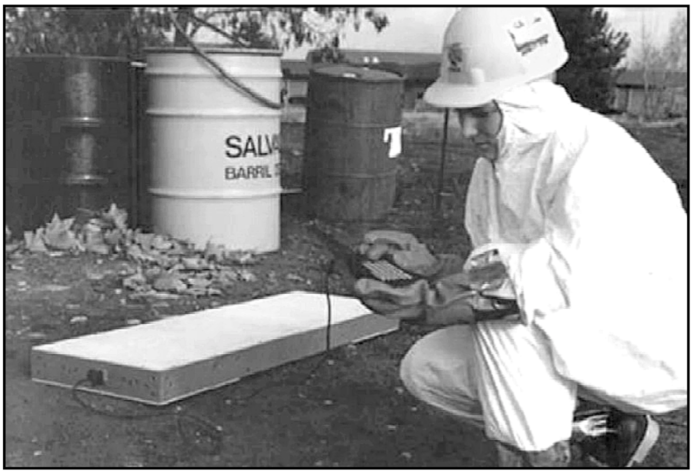


Fig. 4. The BetaScint™ Fiber-Optic Sensor minimizes costly sampling and analysis by allowing a technician to locate strontium-90 and uranium-238 on soils and pavements. The conventional method obtains samples for later offsite laboratory analysis. This sensor reveals the presence of beta emitters in real time, resulting in cost and scheduling benefits. (TechID 70)

Until a recent change in policy, the treatment of choice for mixed wastes containing organic constituents was to have been thermal treatment at DOE incinerators. To better comply with evolving U.S. Environmental Protection Agency emission control regulations, continuous emissions monitors (CEMs) started being developed to augment existing emission sampling technologies that rely on periodically sampling and analyzing stack emissions, with data becoming available only after a substantial time lapse. Similar requirements are anticipated for monitoring the alternative oxidation treatment processes expected to supplant incineration as well as gas effluents from other treatment processes. CEMs must be capable of continuously analyzing what is in the emissions and measuring the amounts of those substances. In particular, CEMs must be capable of measuring, in real time and under adverse conditions, emissions containing low levels of the metals specified in the Resource Conservation and Recovery Act (RCRA), hazardous chemical compounds, and radioactive elements from the incineration of mixed wastes and other effluent-generating treatment processes. CEMs must also provide facility operators with real-time data suitable for certifying compliance with regulatory standards.

Integrating the Program

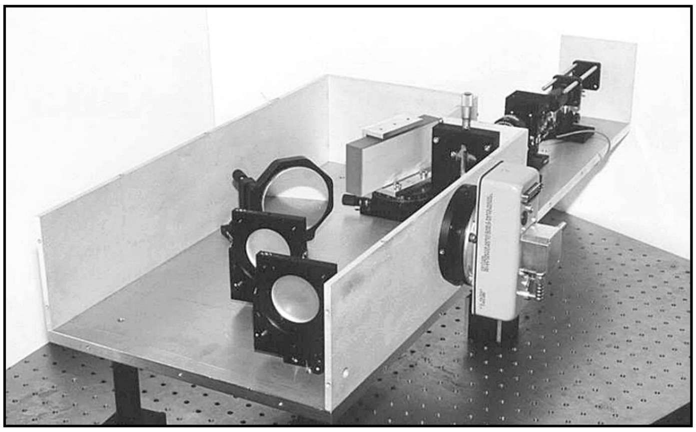
Technology development is proceeding at a rapid pace at various commercial, academic, and federal laboratory organizations. The diversity of those development activities makes it desirable to have a team devoted to overseeing and coordinating DOE-sponsored technology development to avoid duplication of effort, provide expertise, bring in technologies and strategies from other government agencies, and help refine and then satisfy the environmental technology needs of DOE sites. Indeed, a characterization, monitoring, and sensor technology program driven by DOE needs is essential for sensible and cost-effective resource allocation and management. Furthermore, in addition to efficient resource utilization, there is great potential to improve worker safety and to lessen environmental impacts.

Program Scope

The ERWM and OTD and their successors, the Office of Environmental Management (DOE EM) and the Office of Science and Technology (OST), made CMST the focal point for developing the environmental characterization and measurement technologies and methodologies needed for site cleanup. In its role as an integrator of technology development, CMST-CP employed the participation of characterization technical support groups and integrated program technology support groups. CMST-

CP has been active in providing support to the DOE sites through integrated programs, integrated demonstrations, and, under the current focus area–centered approach, focus area technical assistance activities.

The scope of CMST-CP technical support and expertise encompasses the broad spectrum of chemical and physical measurement and analysis technologies and their implementation. These technology solutions are identified and/or developed, demonstrated, and deployed to characterize and monitor contaminant materials, waste streams, and environmental contamination at DOE sites. Figures 1–6 are representative of the technology solutions CMST-CP played an important role in developing. Innovative Technology Summary Reports on these technologies can be accessed by their TechID number (provided at the end of the figure caption) at the following web addresses: www.cmst.org/ or ost.em.doe.gov/.

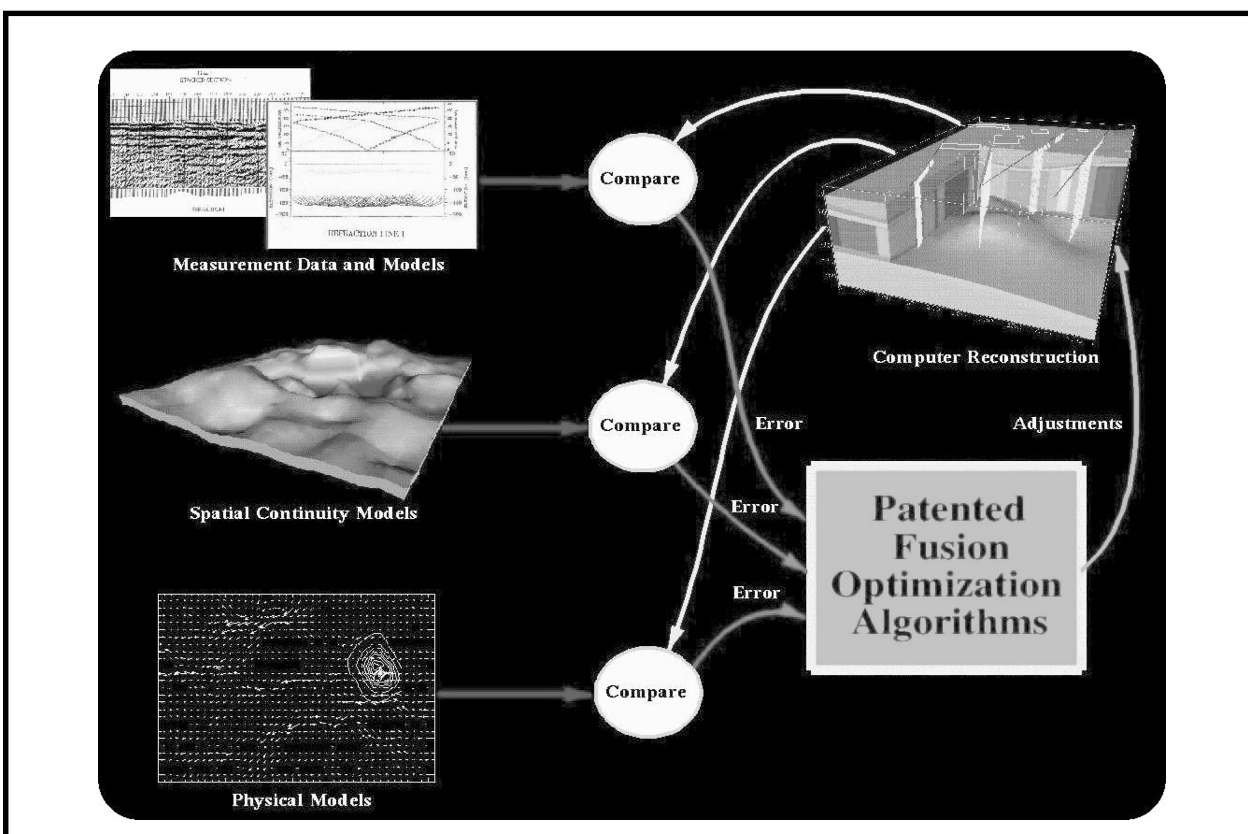


▲ *Fig. 5. The Compact High Resolution Spectrometer is a versatile optical spectrometer for use in field and process applications. This real-time monitor can analyze actinides and continuously monitor EPA-regulated toxic metals, uranium isotopes, and actinides in stack gases. Cost savings result from on-line process control and reducing the need for intensive front-end waste characterization. (TechID 1564)*

The involvement of CMST-CP staff in supporting the OST focus areas and program offices ranges from the identification and analysis of site needs and technology gaps to the delivery and postapplication evaluation of technology performance. CMST-CP provides its technical support and expertise through its technical management staff, which includes focus area liaisons and project facilitators. The technologies and methodologies developed are frequently transferred to industry.

Current Program Status and Future Outlook

Research and development sponsored by CMST has resulted in the evaluation, development, and application of many characterization, monitoring, and sensor technology



▲ *Fig. 6. Hydrogeologic Data Fusion is a mathematical tool used to combine various types of geophysical, geological, and hydrological data from multiple sensors to estimate geological and hydrological properties. It is used to provide superior estimates of model parameters as well as uncertainty in parameter estimation, parameter correlation, and contaminant transport prediction. It provides an organized and defensible means of comparing and correlating the data from various sources. (TechID 2944)* solutions to environmental restoration and waste management needs at DOE sites. The CMST-CP team participates in developing technology solutions to satisfy specific needs identified by the DOE Site Technology Coordination Groups. It strives to develop technological systems that are safer, faster, less costly, more efficacious, and less physically invasive than previously used approaches and to develop solutions where none previously existed. The figures accompanying this article exhibit just a few of these technologies.

Over the past decade, CMST projects have made major technological advances in methods used for site, facility, and waste characterization. They have made a major impact in the areas of real-time in situ monitoring and data acquisition and analysis for site characterization, waste stream and thermal treatment process control, and surveying contaminated facilities and equipment.

At present approximately 120 CMST technologies have been evaluated and/or developed, demonstrated, and applied to DOE EM cleanup needs at DOE sites. Approximately 40 technologies developed by the CMST program are commercially available. Nevertheless, there remain dozens of environmental cleanup situations that need better solutions.

Accurate characterization of the nature and extent of soil, groundwater, and facility contamination can have a dramatic effect on the amount of material that is ultimately subjected to remediation, stabilization, and/or disposal. Treatment options depend to a large extent on accurately determining the distributions and concentrations of various contaminants. Similarly, real-time control and optimization of waste treatment systems can be accomplished only if reliable, real-time monitors are available, thus enabling continuous monitoring and adjustments for changing waste conditions. CMST-CP will continue to play a major role in developing integrated technology systems that provide DOE EM with the capabilities and methods necessary to accomplish its mission.

Finally, DOE EM will need to develop strategies for the challenges posed by long-term stewardship. CMST-CP will play an important role in developing the means for validating system performance upon completion of site remediation and waste disposal. Long-term stewardship will require sensitive and reliable integrated monitoring systems that are cost-effective. The data generated by these systems must be verifiable and defensible in order to protect public health and assure the necessary high confidence in engineered solutions.

The National Research Council[3] recently identified a number of specific measurement technology development needs:

> Development of methods for designing monitoring systems to detect current conditions and changes in system behaviors. These methods may involve the application of conceptual, mathematical, and statistical models to determine the types and locations of observation systems and prediction of the spatial and temporal resolutions at which observations need to be made.
>
> Research to support the development of methods to monitor fluid and gaseous fluxes through the unsaturated zone, including both direct (e.g., in situ sensors) and indirect (e.g., using plants and animals) over long time periods. Included

is research addressing physical instrumentation as well as measurement techniques, the latter including measurement strategies and data analysis (including statistical) approaches.

According to the National Research Council report, research and development continues to be needed to design both in situ and remote sensors that can discriminate more effectively, have greater sensitivity, and enable real-time or near real-time continuous assessments of changing conditions spanning many channels of input (corresponding to many contaminants under observation). Corresponding applied and developmental research is needed to transform the findings of basic research and innovative concepts into functioning, reliable instruments and methodologies for confronting the challenges and demands of in situ applications both in the field or within active or closed facilities. Site monitoring capabilities and strategies will assume even greater importance as cleanup activities draw to a close and DOE enters into a long-term stewardship mode at those sites that will not be able to be released for unrestricted use. Consequently, CMST-CP will become increasingly involved in developing the hardware and software systems and strategies necessary to provide the Office of Long-Term Stewardship with the capabilities it needs to carry out its mission.

The CMST-CP will continue to provide technical CMST support and expertise in developing better technological solutions for site characterization and remediation, facility deactivation and decommissioning, waste and nuclear materials treatment and disposal, and subsurface monitoring and site stewardship. Furthermore, CMST-CP will continue to provide ongoing support to the OST focus areas and program offices for needs assessment, technical response generation, site assistance for demonstrations and deployments, and participation in technical assistance teams, expanding on its proven record of experience and technical capability in delivering innovative technologies to satisfy DOE site characterization, monitoring, and sensor technology needs.

References

1. DOE Environmental Restoration and Waste Management Five-Year Plan, Fiscal Years 1992–96, p. xii (June 1990).

2. DOE Environmental Restoration and Waste Management Five-Year Plan, Fiscal Years 1992–96, p. 194 (June 1990).

3. National Research Council, *Research Needs in Subsurface Science* (2000). ■

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