ROBOTICS CROSSCUTTING PROGRAM

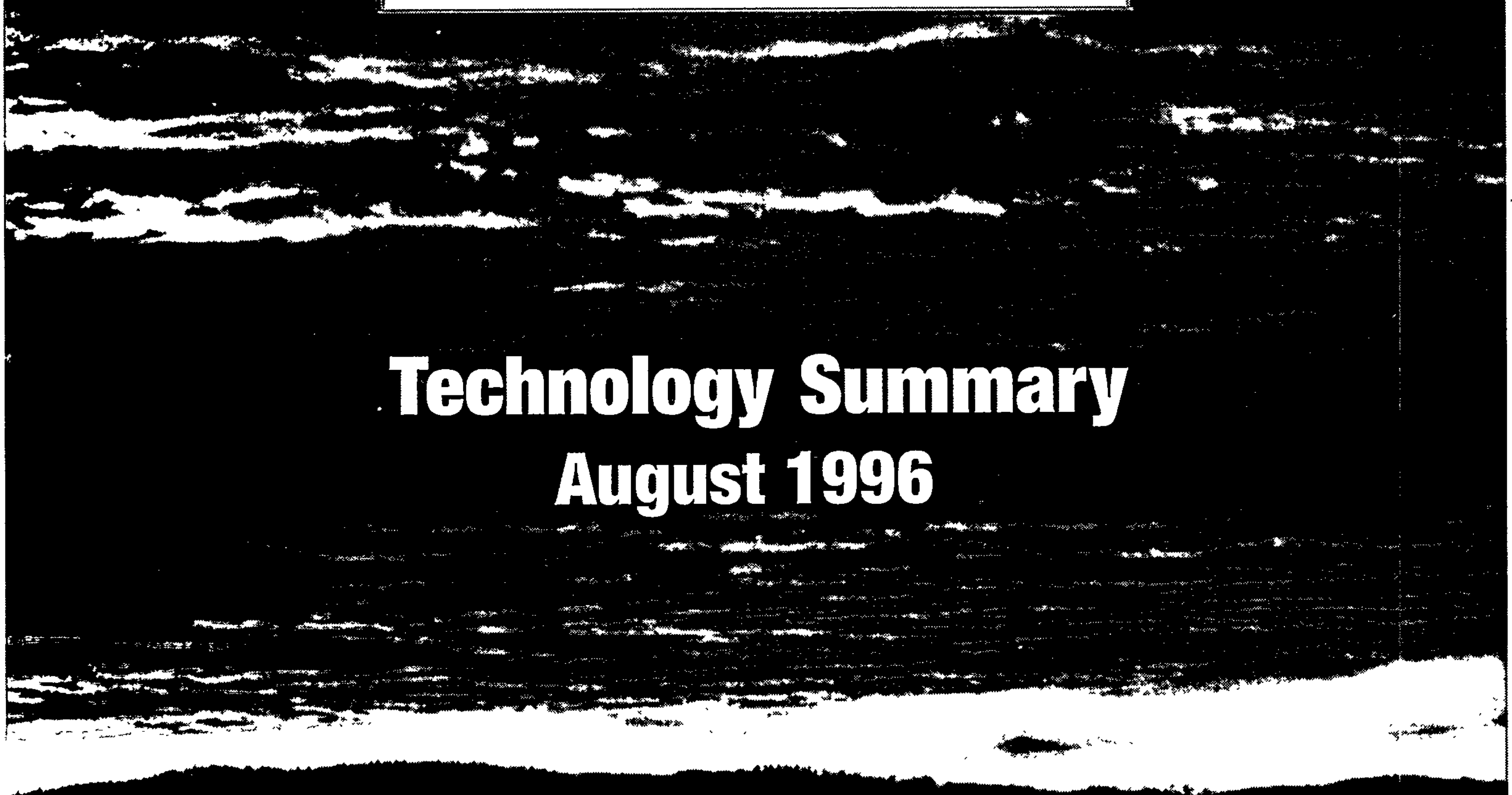
Technology Summary
August 1996

Prepared by the Office of Science and Technology

DOE/EM-0299

Pnnted with soy ink on recycled paper

ROBOTICS CROSSCUTTING PROGRAM



Technology Summary
August 1996

The information in this book represents information available and current through February 1996.

Robotics Crosscutting Program Technology Summary

Table of Contents

.96-0157

FIGURES

INTRODUCTION

The Office of Environmental Management (EM) is responsible for cleaning up the legacy of radioactive and chemically hazardous waste at contaminated sites and facilities throughout the U.S. Department of Energy (DOE) nuclear weapons complex, preventing further environmental contamination, and instituting responsible environmental management. Initial efforts to achieve this mission resulted in the establishment of environmental restoration and waste management programs. However, as EM began to execute its responsibilities, decision makers became aware that the complexity and magnitude of this mission could not be achieved efficiently, affordably, safely, or reasonably with existing technology.

Once the need for advanced cleanup technologies became evident, EM established an aggressive, innovative program of applied research and technology development. The Office of Technology Development (OTD) was established in November 1989 to advance new and improved environmental restoration and waste management technologies that would reduce risks to workers, the public, and the environment; reduce cleanup costs; and devise methods to correct cleanup problems that currently have no solutions.

In 1996, OTD added two new responsibilities—management of a Congressionally mandated environmental science program and development of risk policy, requirements, and guidance. OTD was renamed the Office of Science and Technology (OST).

THE EM ORGANIZATION

OST is one of seven Deputy Assistant Secretarial Offices within EM. Each Deputy Assistant Secretarial Office is discussed here, with the exception of OST (EM-50), addressed in detail later in this Introduction.

Office of the Assistant Secretary for Environmental Management (EM-1)
The Office of the Assistant Secretary for Environmental Management provides centralized direction for waste management operations, environmental restoration, and related applied research and development programs and activities within DOE. The Office of the Assistant Secretary develops EM program policy and guidance for the assessment and cleanup of inactive waste sites and facilities, and waste management operations; develops and implements an applied waste research and development program to provide innovative environmental technologies to yield permanent disposal solutions at reduced costs; and oversees the transition of contaminated facilities from various departmental programs to environmental restoration. The Assistant Secretary provides guidance to all DOE Operations Offices. Organizational relationships are shown in Figure A.

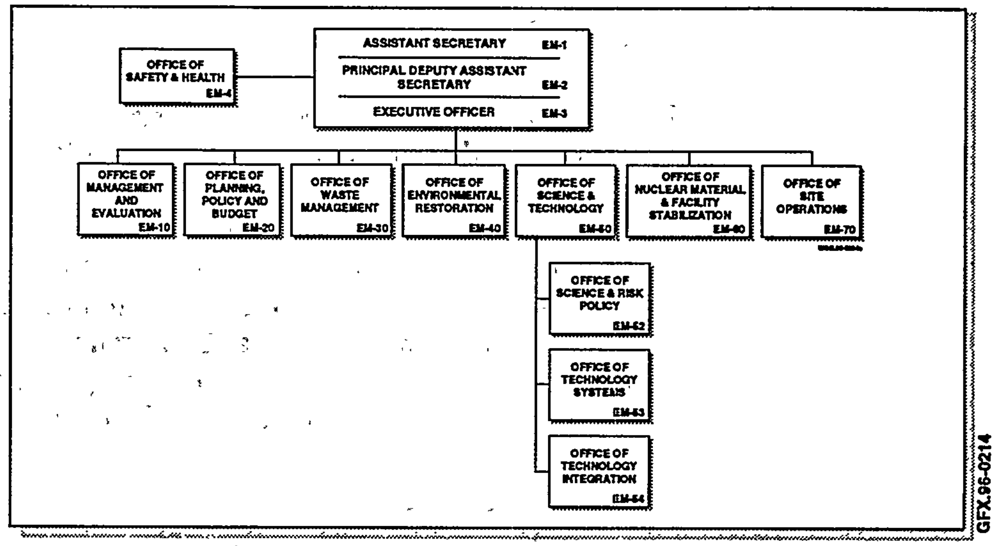


Figure A. Office of Environmental Management Organization Chart

The Office of Management and Evaluation (EM-10)

The Deputy Assistant Secretary for Management and Evaluation serves as the Assistant Secretary's principal advisor on all administrative functions and activities for EM line offices. Responsibilities include personnel administration; training and career development; total quality management; organization and manpower management; cost and performance management; space and logistics management; acquisition, procurement, and contracts management; general administrative support services; and automated data processing, automated office support systems, and information resources management.

The Office of Planning, Policy, and Budget (EM-20)

The Office of Planning, Policy, and Budget analyzes and provides support on policy and planning issues associated with environmental compliance and cleanup activities, waste management, nuclear materials and facilities stabilization, overall budget and priority setting analyses, nuclear nonproliferation policy practices, and the ultimate disposition of surplus materials and facilities. This Office is also responsible for the review, coordination, and integration of inter-site, interagency and international planning activities related to these issues. The Office coordinates policy and procedural issues associated with the external regulation of the environmental restoration, waste management, and nuclear materials and facility stabilization programs.

The Office of Waste Management (EM-30)

The Office of Waste Management provides an effective and efficient system that minimizes, treats, stores, and disposes of DOE waste as soon as possible in order to protect people and the environment from the hazards of those wastes. The Office carries out program planning and budgeting, evaluation and intervention, and representation functions associated with management of radioactive high-level, transuranic, and low-level waste; hazardous and sanitary waste; and mixed waste.

The Office of Environmental Restoration (EM-40)

The Office of Environmental Restoration remediates departmental sites and facilities to protect human health and the environment from the risks posed by inactive and surplus DOE facilities and restores contaminated areas for future beneficial use. This Office provides program direction for and management of environmental restoration activities involving inactive sites and facilities, including the decontamination of surplus facilities.

The Office of Nuclear Material and Facility Stabilization (EM-60)

The Nuclear Material and Facility Stabilization program mission is to protect people and the environment from the hazards of nuclear materials and to deactivate surplus facilities in a cost-effective manner. The Office provides program planning and budgeting, evaluation and intervention, and representation functions associated with the stabilization of nuclear materials and the deactivation of surplus facilities.

The Office of Site Operations (EM-70)

Acting to eliminate barriers and ensure that field concerns are recognized in major EM decisions, the Office of Site Operations acts as a focal point and champion for the Operations Offices and field sites, serving as facilitator, coordinator and ombudsman for crosscutting issues and topics raised by the various EM elements. The Office of Site Operations provides Headquarters policy direction for landlord planning and budgeting and sets policy and guidance to improve the effectiveness of crosscutting environment, transportation management, and waste minimization activities.

The Office of Science and Technology (EM-50)

OST manages and directs focused, solution-oriented national technology development programs to support EM by using a systems approach to reduce waste management life-cycle costs and risks to people and the environment. OST programs involve research, development, demonstration, testing, and evaluation of innovative technologies and technology systems that meet end-user needs for regulatory compliance. Activities include coordination with other stakeholders and the private sector, as well as collaboration with international organizations. In 1994, the EM program identified five major problem areas on which to focus its technology development activities (later two were combined), and implemented Focus Areas to address these problems. In addition, some needs were identified that were common to all the Focus Areas, and three Crosscutting Programs were created to address them.

OST programs establish, manage, and direct targeted, long-term research programs to bridge the gap between broad fundamental research that has wide-ranging application and needs-driven applied technology development research. OST expects to produce technologies to answer the needs of its major customers within EM for innovative science and technology through

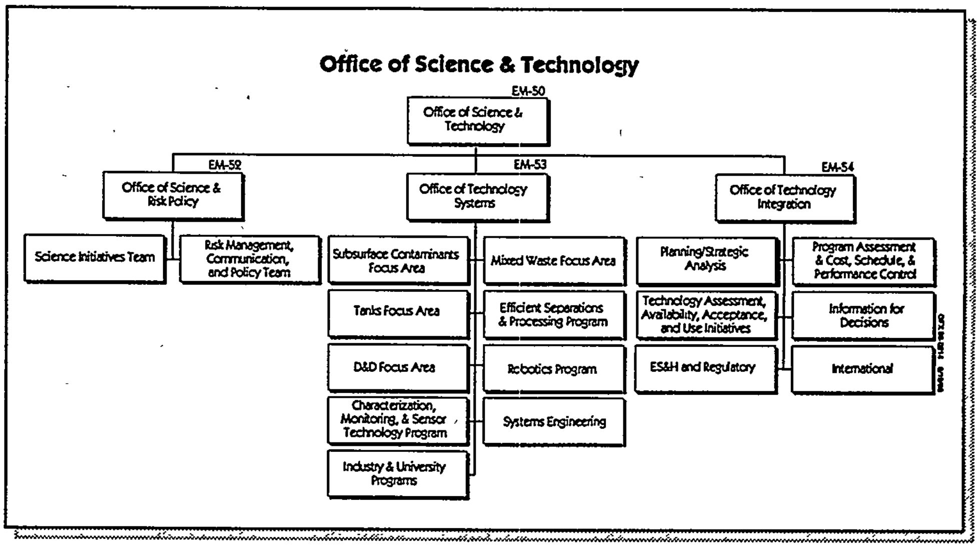


Figure B. Organization Chart of the Office of Science and Technology

integration of basic research programs, applied research programs (Focus Areas and Crosscutting Programs), industry partnerships, and technology transfer activities.

Three offices comprise OST: the Office of Science and Risk Policy, the Office of Technology Systems, and the Office of Technology Integration. The organization for OST is shown in Figure B.

Office of Science and Risk Policy (EM-52)

The Office of Science and Risk Policy manages EM's Science Program and the formulation of risk policy. The mission of this office includes the development of a targeted, long-term basic research agenda for environmental problems so that "transformational" or breakthrough approaches can lead to significant reduction in the costs and risks associated with the EM Program. This Office also bridges the gap between broad fundamental research that has wide-ranging applicability, such as that performed in DOE's Office of Energy Research, and needs-driven applied technology development that is conducted in EM's Office of Technology Systems. This Office was designed to focus the country's science infrastructure on critical national environmental management problems.

The Science Program draws on information from its DOE customers to identify necessary basic research. The Science Program concentrates its efforts on the characterization of DOE's wastes and contaminants, interactions of radioactive elements with biosystems in various natural media and waste forms, extraction and separation of radioactive and hazardous chemical contaminants, prediction and measurement of contaminant movement in DOE facilities' environments, and formulation of scientific bases for the risks associated with DOE-based contaminants.

Risk policy activities within this Office involve the development of policies, procedures, and guidance to ensure that EM activities in preventing risks to the public, workers, and the environment are within prescribed, acceptable levels. Risk evaluation methods and event and consequence analyses provide DOE with a basis for assessing both the risk and any actions being considered to reduce that risk. The Office of Science and Risk Policy ensures that advances in risk evaluation methods are integrated into coherent decision-making processes regarding risk acceptability. Decision-making processes must meet DOE missions while protecting public health, worker health and safety, ecosystem viability, and cultural and national resources.

Office of Technology Systems (EM-53)

OST programs involve research, development, demonstration, testing, and evaluation activities designed to produce innovative technologies and technology systems to meet national needs for regulatory compliance, lower life-cycle costs, and reduced risks to the environment. To optimize resources, OST has streamlined technology management activities into a single focus team for each major problem area. To ensure programs are based upon user needs, these teams include representatives from user offices within EM. There are four major problem areas upon which technology development activities are focused.

- Mixed Waste Characterization, Treatment, and Disposal
- Radioactive Tank Waste Remediation
- Subsurface Contaminants
- Decontamination and Decommissioning

Mixed Waste Characterization, Treatment, and Disposal Focus Area

DOE stores 167,000 cubic meters of mixed low-level and transuranic waste from over 1,400 mixed radioactive and hazardous waste streams at 38 sites. The Mixed Waste Characterization, Treatment, and Disposal Focus Area provides an integrated, multi-organizational, national team to develop treatment systems for the department's inventory of mixed radioactive and hazardous waste and to dispose of these low-level and transuranic waste streams in a manner that regulatory requirements.

This Focus Area plans to demonstrate three technologies to treat at least 90 percent of DOE's stored mixed waste inventory by the end of FY97. The outcome will be waste forms that are reduced in volume, as compared to the volume of stored mixed waste, and meet regulatory requirements for safe, permanent disposal. Technology development is being conducted in the areas of thermal and nonthermal treatment emissions, nonintrusive drum characterization, material handling, and final waste forms.

Radioactive Tank Waste Remediation Focus Area
The Radioactive Tank Waste Remediation Focus Area develops technologies to safely and efficiently remediate over 300 underground storage tanks that have been used to process and store more than 100 million gallons of high-level radioactive and chemical mixed waste. Technologies are needed to characterize, retrieve, and treat the waste before radioactive components are immobilized. All this must be done in a safe working environment. Emphasis is placed on in situ or remotely handled processes and waste volume minimization.

Research and development of technologies in this area is aimed at enabling tank farm closure using safe and cost-efficient solutions that are acceptable to the public and that fulfill Federal Facility Compliance Act requirements of site regulatory agreements.

Subsurface Contaminants Focus Area
The Subsurface Contaminants Focus Area is developing technologies to address environmental problems associated with hazardous and radioactive contaminants in soil and groundwater that exist throughout the DOE complex, including radionuclides, heavy metals, and dense, nonaqueous phase liquids. More than 5,700 known DOE groundwater plumes have contaminated over 600 billion gallons of water and 50 million cubic meters of soil. Migration of these plumes threatens local and regional water sources, and in some cases has already adversely impacted off-site resources. In addition, the Subsurface Contaminants Focus Area is responsible for supplying technologies for the remediation of numerous landfills at DOE facilities. These landfills are estimated to contain over 3 million cubic meters of radioactive and hazardous buried waste, some of which has migrated to the surrounding soils and groundwater. Technology developed within this specialty area will provide effective methods to contain contaminant plumes and new or alternative technologies for remediating contaminated soils and groundwater. Emphasis is placed on the development of in situ technologies to minimize waste disposal costs and potential worker exposure by treating plumes in place. While addressing contaminant plumes emanating from DOE landfills, the Subsurface Contaminants Focus Area is also working to develop new or alternative technologies for the in situ stabilization and nonintrusive characterization of these disposal sites.

Decontamination and Decommissioning Focus Area
The Decontamination and Decommissioning Focus Area is developing technologies to solve the department's challenge of deactivating 7,000

contaminated buildings and decommissioning 700 contaminated buildings. It is also responsible for decontaminating the metal and concrete within those buildings and disposing of 180,000 metric tons of scrap metal. Technology development for decontamination and decommissioning focuses on large-scale demonstrations, each of which incorporates improved technologies identified as responsive to high-priority needs. All technologies will be considered for eventual deployment, and side-by-side comparisons of improved technologies are being performed using existing commercial technologies as baselines.

Crosscutting Programs

In addition to work directed to specific Focus Areas, EM is engaged in research and development programs that cut across these problem areas. Technologies from these Crosscutting Programs may be used within two or more of the Focus Areas to help meet program goals. These programs complement and facilitate technology development in the Focus Areas as shown in Figure C. The Crosscutting Programs are:

- Characterization, Monitoring, and Sensor Technologies,
- Efficient Separations and Processing, and
- Robotics Technology Development Program.

Characterization, Monitoring, and Sensor Technologies Crosscutting Program

DOE is required to characterize more than 3,700 contaminated sites, 1.5 million barrels of stored waste, 385,000 m^3 of high-level waste in tanks, and from 1,700 to 7,000 facilities before remediation, treatment, and facility transitioning commence. Monitoring technologies are needed to ensure worker safety and effective cleanup during remediation, treatment, and site closure.

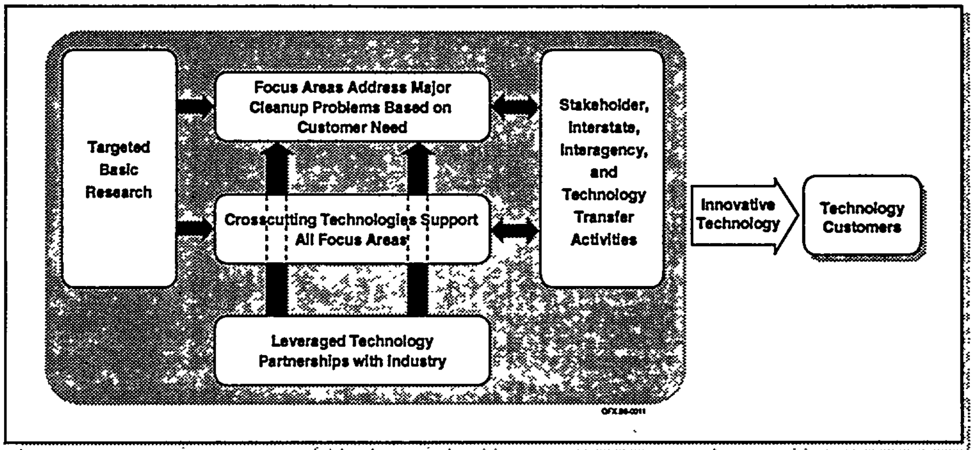


Figure C. Relationships between Focus Areas and Crosscutting Programs

Efficient Separations and Processing Crosscutting Program

Separations and selected treatment processes are needed to treat and immobilize a broad range of radioactive wastes. In some cases, treatment technologies do not exist; in others, improvements are needed to reduce costs and secondary waste volumes and to improve waste form quality. This Crosscutting Program concentrates efforts on specific high-priority needs as defined by the Focus Areas, then evaluates and adapts the technologies for other applicable Focus Areas.

This program is working to meet Federal Facilities Compliance Act milestones and other regulatory requirements, and to develop separations and treatment technologies that minimize risk, the volume of waste requiring deep, geological disposal, and secondary waste volumes.

Robotics Technology Development Crosscutting Program

Existing technologies are often inadequate to meet EM's mission needs both at a reasonable cost and under conditions that promote adequate worker safety. Robotic systems reduce worker exposure to the absolute minimum while providing proven, cost-effective, and, in some cases, the only acceptable approach to problems.

Robotics remote systems development work occurs in three areas. Remote systems for decontamination and dismantlement of facilities will reduce or eliminate extensive worker radiation protection requirements and increase productivity. Robotic systems for characterization and retrieval of stored tank waste will allow work to proceed within the radiation fields in the waste storage area. Automated chemical/radiological analysis systems are estimated to provide a cost benefit of $10.5 billion from FY96 through FY00.

INDUSTRY AND UNIVERSITY PROGRAMS

Industry and University programs provide to the Focus Areas and the Crosscutting Programs the capability to involve private industry, universities, and other interested parties in their program through direct procurement with DOE. The public-private partnerships that are established encourage the enhancement and commercialization of technologies developed by the private sector through pilot- and field-scale demonstration at DOE sites. The integration of industry, academia, and the DOE laboratories allows all aspects of the technology to be evaluated, including worker safety and health, commercial potential, and technical merit.

Industry and University activities support more than 100 agreements with the private sector. These agreements include the Small Business Innovative Research (SBIR) program, international activities, stakeholder activities, worker safety and health activities, and commercialization initiatives, as well as the direct support to the Focus Areas. For information on how to participate in these programs, see the "DOE Business Opportunities" section at the end of this book.

Office of Technology Integration (EM-54)

The Office of Technology Integration addresses issues that affect the involvement of critical external entities such as production/waste sites, users, the public, tribes, regulators, and commercial parties. The office is involved in the assessment, acceptability, availability, and use of improved technical solutions by providing uniform guidance, tools, and initiatives to support the Office of Technology Systems. This office also sponsors efforts to encourage and promote the involvement of affected parties' in regulatory issues.

In addition, the Office of Technology Integration sponsors domestic and international technology transfer programs within OST and coordinates planning and cost-benefit analyses with other EM organizations.

ROBOTICS TECHNOLOGY DEVELOPMENT PROGRAM

PROGRAM OVERVIEW

The Robotics Technology Development Program (RTDP) is a needs-driven effort. A lengthy series of presentations and discussions at DOE sites considered critical to DOE's Environmental Management (EM) Programs resulted in a clear understanding of needed robotics applications toward resolving defined problems at the sites. A detailed analysis of the resulting robotics needs assessment revealed several common threads running through the sites: Tank Waste Retrieval (TWR), Chemical Analysis Automation (CAA), and Decontamination & Dismantlement (D&D). The RTDP Group also realized that some of the technology development in these three areas had common needs: for example, computer control and sensor interface protocols. Further, the Office of Science and Technology's (OST) approach to the research, development, demonstration, testing, and evaluation process urged an additional organizational breakdown between short-term (1-3 years) and long-term (3-5 years) efforts. These factors led to the formation of the fourth application area for Crosscutting and Advanced Technology (CC&AT) development. The RTDP is thus organized around these application areas— TWR, CAA, D&D, and CC&AT – with the first three developing short-term applied robotics.

Each application area is coordinated by a DOE contractor at a site/laboratory chosen for its unique expertise or situation as paradigmatic of an EM problem. The coordinator leads an integrated, multi-member team of experts chosen from throughout the DOE complex, private industry, and universities.

The DOE Headquarters Robotics Program Manager is responsible for higher level management of the entire program with consultations throughout EM and frequent interactions with coordinators. Overall program direction, as reflected in fiscal emphasis, is a primary headquarters responsibility. Another responsibility is program integration among the RTDP application areas, various OST activities supported by the RTDP, and non-OST offices in EM. Program integration is critical to maximize resources to meet user's needs. The Robotics Program Manager's function can summarily be stated as directly managing the RTDP so as to develop and demonstrate effective robotics systems, defined as needed by the customer programs, through a complex-wide, integrated approach.

The technology development and program management approach followed by the RTDP can be expressed as:

1) TEAMS: pull together the best from DOE National Laboratories, industries, and universities

2) BROAD APPLICABILITY: focused projects to solve complex-wide problems

3) NEEDS-DRIVEN: direct contact with sites and customer programs to build required systems

4) EXTERNAL INTEGRATION: each part of the RTDP is directly mapped onto the OST Focus Area organization

5) INTERNAL INTEGRATION: emphasis on solutions to common problems within the RTDP for application to customer programs

6) NATIONAL PERSPECTIVE: address complex-wide solutions through direct interaction with DOE HQ

A brief description of each technical application area appears below, with detailed discussion of each area in subsequent chapters of this book:

Tank Waste Retrieval (TWR): The TWR Team develops storage tank characterization and retrieval technology using long-reach robot manipulators. The TWR Team is developing a full-scale test bed to examine single and multiple arm concepts. Characterization and retrieval end-effectors with automated control and advanced graphic interfaces are particularly significant.

Chemical Analysis Automation (CAA): The CAA Team develops fully automated modules that perform generic tasks common to analytical chemistry. The modules are chosen for their repeated use in DOE analysis methods and represent a significant fraction of sample load. The underlying theme is "plug-and-play," interface standardization, transportability, architectural openness, and modularity.

Decontamination and Dismantlement (D&D): The D&D Team works on automating the D&D process from surveillance to facility characterization to surface decontamination to hot cell dismantlement. The goal is to maximize efficiency while minimizing human exposure. The work centers around vehicular and crane deployed dual-arm systems using advanced sensors, control, and operator interface technologies.

Crosscutting and Advanced Technology (CC&AT): The CC&AT Team develops technologies used throughout the RTDP. Projects are directed toward a generic, graphical robot controller based on an integrated multisensory system, plus systems analysis and modeling/simulation. Coupling sensor-based modeling with automated programming of robot operations is a key approach to developing faster, safer, and less expensive waste cleanup systems.

CONTACT

Dr. Linton W. Yarbrough
Robotics Program Manager
Energy & Technology Development Division
P.O. Box 5400
Albuquerque, NM 87185-5400
(505) 845-5520
No e-mail available

John De Gregory
Robotics Headquarters Coordinator
U.S. Department of Energy
Cloverleaf Building
19901 Germantown Road
Germantown, MD 20874-1290
(301) 903-7949
e-mail: John.degregory@em.doe.gov

1.0 ROBOTICS TANK WASTE RETRIEVAL OVERVIEW

The Robotics Tank Waste Retrieval (TWR) Team is responsible for developing, testing, and demonstrating robotic technology for characterization and remediation of underground storage tanks. Coordination is the responsibility of Oak Ridge National Laboratory (ORNL), with contributions from the Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratory (SNL). Florida International University and Washington University will also participate. The crosscutting technology developed by TWR is in direct support of the Radioactive Tank Waste Remediation Focus Area (Tanks Focus Area).

Across the DOE complex are hundreds of waste storage tanks that will require remediation during the coming decades. Many of these tanks are already leaking or are out of compliance with current environmental regulations. Typical tanks are between 50 and 80 feet in diameter and have capacities up to one million gallons. Access to the interior of these tanks is limited to a small number of portholes that range from 12 to 42 inches in diameter. For containment purposes, it is desirable to restrict characterization and remediation operations to tasks that can be achieved with the tank domes in place. Because of the high radiation levels at the surface of these tanks and chemical hazards present, it is highly desirable to perform remediation operations remotely. Also, because of the large volumes of waste that must be processed, it is desirable to introduce automated remote operations wherever practical. The application of robotic systems to remediation of waste storage tanks offers opportunities for safer, faster, and cheaper solutions over the duration of these massive cleanup projects.

Although the lines of responsibility between the Tanks Focus Area and TWR are not formally defined, the Tanks Focus Area has generally focused on the waste characterization, retrieval, and treatment processes while the RTDP has generally focused on the robotics tools required to deploy the characterization and retrieval tools. Both programs have funded complementary activities in topographical mapping and data analysis. From FY91 through FY96, TWR developed controls and sensing technology associated with deployment of long-reach, high-capacity manipulator systems. Development of the Modified Light Duty Utility Arm (MLDUA) system by the Tanks Focus Area provides the TWR with a full-scale test bed for evaluating the controls technologies developed over the past few years. Development of vehicle-based retrieval systems and associated controls and sensors has also been traditionally supported by the TWR rather than the Tanks Focus Area. Between FY95 and FY97 the vehicle system development is being performed in collaboration with the Morgantown Energy Technology Center (METC).

Arm-based retrieval will be performed using the MLDUA, a modified version of the Light Duty Utility Arm (LDUA) currently being fabricated by Spar Aerospace Limited for use in tank characterization campaigns by the Westinghouse Hanford Company. Development of the LDUA system is a Tank Focus Area project being leveraged by ORNL. Like the Westinghouse Hanford Company LDUA, the MLDUA will consist of a dual section, telescoping vertical mast, a five link arm, a deployment and containment system, and remote control capabilities. The system will have eight degrees of freedom and is intended for operation essentially in a Selective Compliance Assembly Robot Arm at the METC configuration after deployment, as shown in Figure 1.0-1.

The two most significant modifications required to support the waste retrieval mission for the ORNL Gunite tanks include an increased payload from 75 to 200 lbs., and an extended reach from 13.5 to 15.0 feet as measured from shoulder joint to the tool interface plate. A tool interface plate complete with pneumatic/hydraulic connections will allow the use of a variety of tools or end-effectors, including a gripper end-effector capable of operating with the increased payload. The gripper end-effector and beefed-up payload are necessary to manipulate a separate confined-sluicing end-effector and waste conveyance system for cutting, dislodging, and removing radioactive waste. The extended reach of the MLDUA is desirable to allow maximum coverage of the tank walls and floor while minimizing the number, and thus the associated cost, of new risers that must be installed in the tanks.

As delivered from Spar Aerospace Limited, the MLDUA will be capable of teleoperation from a control trailer and will include an interface to provide

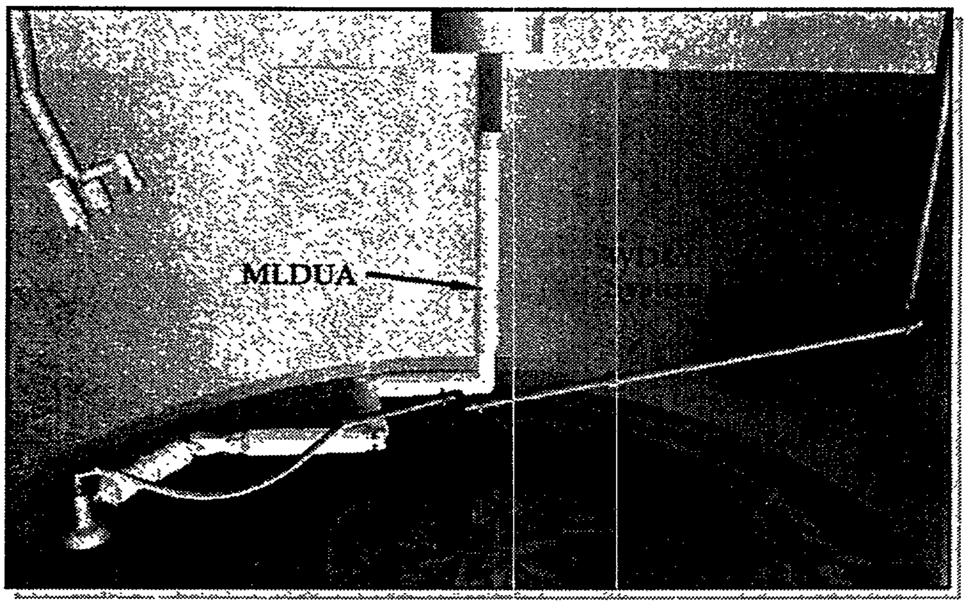


Figure 1.0-1. Manipulator-based Retrieval System Concept.

sensor data to, and accept position commands from, a higher level control system. The RTDP is funding development of several enhancements to this Spar control system, all of which will be integrated with the original control system upon delivery of the MLDUA to ORNL. Enhancements sponsored by the RTDP include a flexible structure damping algorithm, currently under development at PNNL and ORNL, which will be used to improve MLDUA position control by compensating for structural deflections of the manipulator system. In addition, Washington University is developing a function-based sharing control scheme and a new sensor-based control method for impact control and force regulation as added safety features for the MLDUA.

The RTDP is also designing and building an end-effector for characterizing the residual contamination on tank floors and walls after waste retrieval.

Early studies indicate that the original cost estimate of $400 million for full remediation of Gunite tanks can be reduced by at least a factor of four through careful evaluation of the treatment alternatives and application of the appropriate remote retrieval systems. Teaming of the ORNL Environmental Restoration Program with the Office of Science and Technology (OST) Tanks Focus Area and RTDP allows for considerable cost savings during the design and operations phases. ORNL's commitment to field evaluation and integration of OST technologies affords the opportunity to pioneer use of these technologies for ORNL and the rest of the DOE complex.

CONTACT

Barry L. Burks, Ph.D.
Tank Waste Retrieval Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Bldg. 7601, MS 6304
Oak Ridge, TN 37831-6304
(423) 576-7350
e-mail: burksbl@ornl.gov

1.1 RESIDUAL CONTAMINATION SURVEY END-EFFECTOR

TECHNOLOGY NEED

During the first half of FY97, the Gunite and Associated Tanks Treatability Study will remove sludge waste from two tanks in Oak Ridge. Even after sludge waste is retrieved from these Gunite tanks, some level of contamination will remain in the walls, floor, supernatant liquid, and residual sludge. In order to first determine "how clean" the tanks are and then eventually establish closure criteria for successful remediation of all Gunite tanks at ORNL, a multi-purpose end-effector is required for deployment by either the Modified Light Duty Utility Arm (MLDUA) or a vehicle-based system.

TECHNOLOGY DESCRIPTION

A manipulator end-effector capable of measuring residual contamination on tank floors and walls is being developed. This end-effector will be deployed before, during, and after waste retrieval operations to locate and measure residual contamination sources. Conceptual drawings of the end-effector are shown in Figures 1.1-1 and 1.1-2.

BENEFITS

The technology development performed in the TWR area is tightly coupled with EM-40 activities at the ORNL site. The residual contamination survey end-effector will be necessary to quantify the effectiveness of sludge waste retrieval

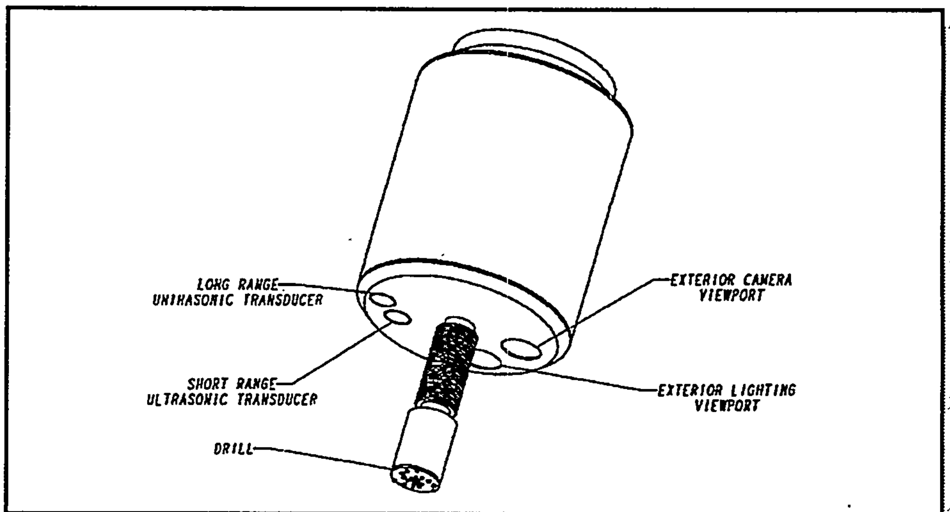


Figure 1.1-1. Exterior View of Residual Contamination Survey End-Effector.

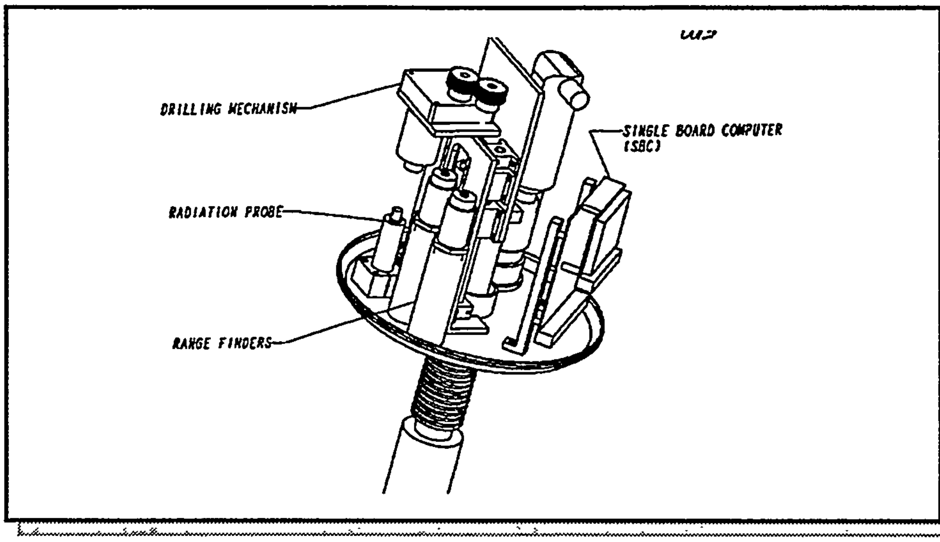


Figure 1.1-2. Interior View of Residual Contamination Survey End-Effector.

from the Gunite tanks and will also be used to determine how much, if any, tank floor and wall surface cleaning will be required to reduce residual contamination below risk criteria.

Collaboration/Technology Transfer

ORNL is collaborating with SNL on the development of the Residual Contamination Survey End-Effector. ORNL is assisting SNL in determining functions and requirements for the residual contamination characterization end-effector and evaluating development options. SNL is responsible for examining the needs associated with the end-effector, and evaluating both commercially available and new technologies to develop a practical conceptual design for the end-effector.

During FY97, the Residual Contamination Survey End-Effector will be used for a commercial-scale demonstration by an EM-40 user as part of the Gunite and Associated Tanks Treatability Study in Oak Ridge, Tennessee. Because of the near-term deployment aspects of this application, the end-effector can be considered available for transfer either through Cooperative Research and Development Agreements or licensing.

Accomplishments

This activity was initiated in FY96. Accomplishments to date include:

- Development of a functions and requirements document in January 1996
- Completion of a conceptual design review for the Residual Contamination Survey End-Effector

TTP Information

Residual Contamination Survey End-Effector activity is funded under the following technical task plans (TTPs):

TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup"

Contacts

Barry L. Burks, Ph.D.
Tank Waste Retrieval Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Bldg. 7601, MS 6304
Oak Ridge, TN 37831-6304
(423) 576-7350
e-mail: burksbl@ornl.gov

Scott E. Slezak
Residual Contamination Survey End-Effector
Principal Investigator
Sandia National Laboratories
Organization 9661, Mail Stop 1177
P.O. Box 5800
Albuquerque, NM 87185-1177
e-mail: sesleza@isrc.sandia.gov

Bibliography of Key Publications

Fischer, G.J., S.E. Slezak, and B.J. Spletzer. *Functions and Requirements for the Oak Ridge Modified Light Duty Utility Arm Minilab End-Effector*. Sandia National Laboratory Report (1996).

1.2 MLDUA CONTROL SYSTEM DEVELOPMENT

TECHNOLOGY NEED

As delivered, the MLDUA will be capable of teleoperation from a control trailer and will include an interface to provide sensor data to, and accept position commands from, a higher level control system. Automated mining is desirable for more efficient operations; however, the control system must be modified such that the operator can intervene to avoid collisions, alter the process for efficiency, and then continue with automated mining.

TECHNOLOGY DESCRIPTION

Flexible manipulator controls algorithms developed by the RTDP over the past several years will be implemented and demonstrated on the MLDUA at ORNL. Oscillation damping will focus on oscillations induced by controlled motion of the MLDUA and dynamic effects induced by a waste dislodging and conveyance end-effector. Controls enhancements will also implement a seamless transition between robotic and teleoperated control allowing an operator to modify a robot trajectory in real time based on hand controller input, and then return to robotic control. Controls enhancements will also allow coordinated control between the MLDUA and the retrieval end-effector hose management system.

BENEFITS

The technology development performed in the TWR area is tightly coupled with EM-40 activities at the ORNL site. The results of the MLDUA control system enhancements will impact efficiency and safety of operations.

COLLABORATION/TECHNOLOGY TRANSFER

ORNL is collaborating with both PNNL and Florida International University on kinematic and dynamic modeling of the MLDUA system. In addition, ORNL is collaborating with PNNL and Washington University on control system enhancements for the MLDUA. ORNL is responsible for generating a functions and requirements document for the MLDUA control system with an emphasis on system enhancements for telerobotic control. In addition, ORNL will produce a schematic diagram illustrating all communications and instrumentation connectivity. Based on this input, PNNL will develop software for control system enhancements by building upon previous work in oscillation damping of flexible structures. These algorithms will be modified for use with the MLDUA. Furthermore, Washington University will develop software for damping of oscillations induced by dynamic payloads and for coordinated motion control of the MLDUA and associated systems.

During the next two fiscal years, the MLDUA control system enhancements will be tested in a commercial-scale demonstration by an EM-40 user as part of the Gunite and Associated Tanks Treatability Study in Oak Ridge, Tennessee. The flexure control algorithms developed under TWR may be considered available for transfer either through Cooperative Research and Development Agreements or licensing.

Accomplishments

This activity was initiated in FY96. Accomplishments to date include:

- Completed functions and requirements document for MLDUA control system
- Initiated kinematic and dynamic modeling efforts
- Completed bench-scale development and testing of active oscillation damping control algorithms
- Completed bench-scale development and testing of a function-based sharing control algorithm

TTP Information

The Modified Light Duty Utility Arm (MLDUA) Control System Development is funded under these two TTPs:

TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. RL35C111, "Robotics PNNL Rollup"

Contact

Barry L. Burks, Ph.D.
Tank Waste Retrieval Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Bldg. 7601, MS 6304
Oak Ridge, TN 37831-6304
(423) 576-7350
e-mail: burksbl@ornl.gov

Bibliography of Key Publications

Babcock, S.M., B. L. Burks, D.D. Falter, P. D. Lloyd, J. D. Randolph, J. E. Rutenber, and S. D. Van Hoesen. "Remote Systems for Waste Retrieval from the Oak Ridge National Laboratory Gunite Tanks," *Proceedings of the ANS 6th Topical Meeting on Robotics & Remote Handling*, Vol. 73, p. 466 (November 1995).

2.0 ROBOTIC CHEMICAL ANALYSIS AUTOMATION

The Chemical Analysis Automation (CAA) Program (previously entitled Contaminant Analysis Automation Program) is one coordination area of the Robotics Technology Development Program (RTDP) within the DOE's Office of Science and Technology. The CAA team's objective is to promote the development and commercialization of chemical analysis and sample preparation technologies necessary for the automation of DOE and private contract environmental laboratories. This effort is in direct response to the tremendous need for chemical characterization of contaminated environmental soil samples, contents of storage tanks, water samples, and other sample matrices under the control of DOE that must take place before remediation can be initiated. The technologies being developed by the CAA team have additional value as commercial products for other chemical applications and laboratories involved in other markets, such as petro-chemical, food and flavorings, cellulose, polymers, and mining.

Within DOE, the automated technology developed by this program is directly applicable to the following Focus Areas:

- Mixed Waste Characterization, Treatment, and Disposal
- Contaminant Plume Containment and Remediation
- Landfill Stabilization

DOE has significant amounts of radioactive and hazardous wastes stored, buried, and still being generated at many sites within the United States. These wastes must be chemically characterized to determine the elemental, isotopic, and compound content before remediation can begin. It is projected that sampling requirements will necessitate generating more than four million samples by the end of 1996, which could exceed the capabilities of current manually driven chemical analysis laboratories. Today, no fully automated commercially available systems are accessible to automate these laboratories.

Initial market surveys revealed that modular and standardized software and hardware instrumentation is needed if DOE laboratories are to have the throughput, reliability, and accuracy required for effective and timely remediation. The benefit in developing modular systems comes from the ease by which a chemist can configure specific chemical methods for processing regulated analysis methods and from the ability of a technician not versed in environmental chemistry to operate these systems without expert consultation. To provide valid data and timely sample analysis results, the CAA team realized that it is necessary to harden these systems so that they can be transported to and operated directly at the remediation site.

The CAA team has made substantial progress towards its goal of automating the environmental analytical laboratory under a standardized and modular paradigm known as the Standard Analysis Method (SAM). The first system, the organic system for PCB analysis in soils has been integrated and tested (Figure 2.0-1). To date, a suite of 14 Standard Laboratory Modules™ (SLM™), the backbone of this integrated technology, has been designed and developed. Also, several detailed surveys of the environmental market and its needs were commissioned to help focus and prioritize development.

The DOE laboratories involved in the CAA effort include Pacific Northwest National Laboratory (PNNL), Idaho National Engineering Laboratory (INEL), Sandia National Laboratories (SNL), Oak Ridge National Laboratory (ORNL), and Los Alamos National Laboratory (LANL) acts as the coordinating laboratory. The participating CAA team-member universities are the Universities of Texas, Tennessee, and Florida. Coordinating the entire CAA team is SciBus Analytical, Inc., a commercialization partner under contract to DOE through a five-year, multi-lab Cooperative Research and Development Agreement (CRADA), initiated in February 1996. This joint CRADA includes an exclusive license to SciBus for the commercialization of this technology.

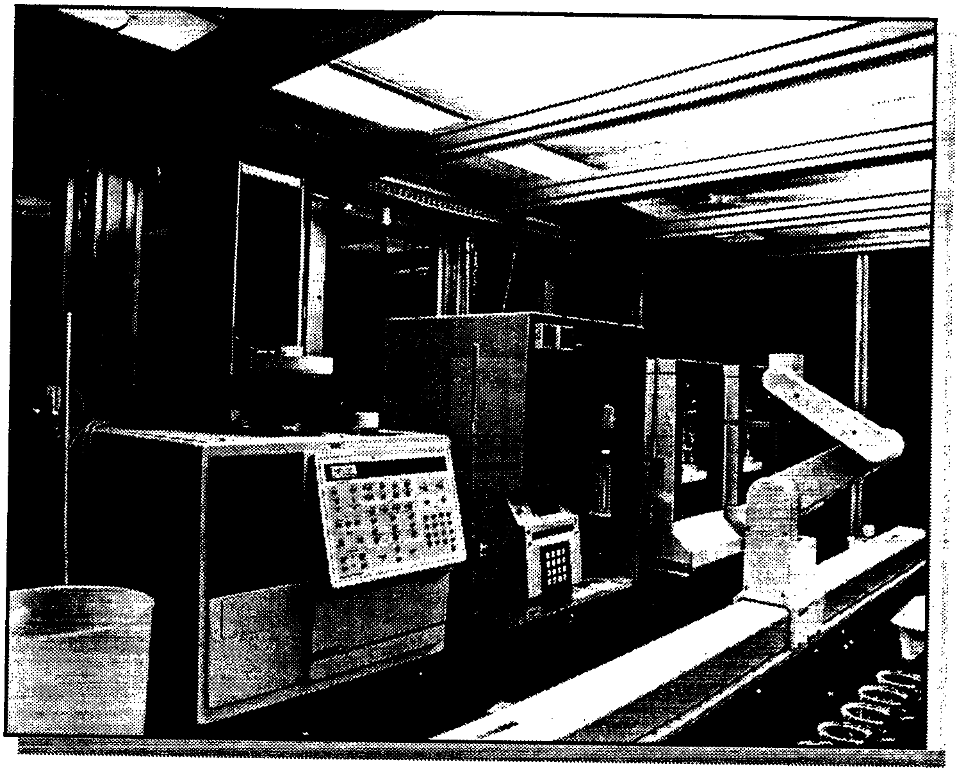


Figure 2.0-1. A robot arm moves a sample through a set of SLMs™, each designed to conduct a specific characterization function.

CONTACT

Robert M. Hollen
Chemical Analysis Automation Coordinator
Los Alamos National Laboratory
P.O. Box 1663, MS:J580
Los Alamos, NM 87545
(505) 667-3186
e-mail: hollen@lanl.gov

2.1 THE STANDARD LABORATORY MODULE™ AND STANDARD ANALYSIS METHOD

TECHNOLOGY NEEDS

The Standard Analysis Method (SAM) is a fumehood-compatible grouping of Standard Laboratory Modules™ (SLMs™) into a system that will automate currently existing regulated chemical methods and future innovative analysis technologies. A graphical representation of the SAM concept is shown in Figure 2.1-1. These SLMs™ behave like modular building blocks easily integrated into SAM systems that would automate a full analysis. The SAM system will accept samples from the field as input. After automated preparation, the samples will be analyzed, and the resulting raw data will be interpreted automatically by an expert system using pattern recognition algorithms. The SAM generates knowledge of the waste site, which is then used for more effective and cheaper remediation. Each SAM system includes a sophisticated, object-oriented database within the system controller that tracks the sample in all phases of analysis so that a detailed audit trail will be accessible for sample integrity and chain of custody verification. The human computer interface (HCI) uses modular, open-architecture software, which allows the HCI to be much more intuitive and facilitates the addition of new or different system capabilities.

The many pervasive impacts of CAA technology are based on its significantly beneficial impact on DOE remediation efforts. By 1995, the projected DOE sampling requirements necessitated generating more than 10 million determinations, which exceeds the current capacity to manually process these samples either within on-site or off-site commercial environmental laboratories. Regulations continue to become progressively more stringent. Some of the known sites requiring remediation include 60,000 U.S. Environmental Protection Agency (EPA) Superfund sites, 2,400 Resource Conservation and Recovery Act (RCRA) sites, 22,000 state-funded sites, 7,200 Department of Defense (DoD) sites, and 100 DOE sites.

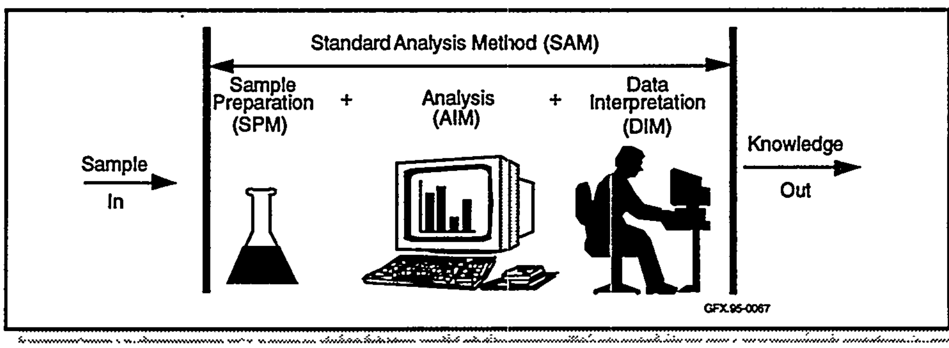


Figure 2.1-1. The Standard Analysis Method (SAM) Concept.

Technology Description

By designing and transferring to industry the various CAA-developed systems based upon the SAM architecture, the CAA group is working towards a standardized and modular approach to laboratory automation. The CAA Program consists of an aggressive team developing automated sample analysis systems for DOE. The CAA Program is also a highly collaborative effort among the engineering teams within the five DOE National Laboratories, three universities, an industrial commercialization partner, and other teams within several private industrial partners. This large team is developing automated sample analysis systems to significantly enhance the remediation efforts of DOE.

The CAA concept allows a chemist to easily assemble an automated environmental analysis system using standardized modules without the worry of hardware or software incompatibility or the necessity of generating complicated control programs. These systems, hardened for the rigors of on-site remediation, will be designed for use within transportable laboratories directly at the remediation site, but will also be used within standard governmental and commercial analytical laboratories.

Benefits

CAA technology creates and accelerates job creation and growth. For example, there are currently 3.5 million people working in the area of environmental site remediation. With CAA technology, this number is expected to grow by 1.5 to 2.4 million more by the late 1990s. More jobs will be created in other areas, as well. In the area of safety, automation accelerates the removal of hazardous waste sites, improves safety in the laboratory by helping limit human exposure to hazardous chemicals, improves characterization accuracy (30% of all analyses are rerun due to operator errors), and directly enhances waste minimization/reduction in the laboratory. CAA technology helps U.S. competitiveness in international markets by maintaining and enhancing the U.S. lead in analytical instrumentation. In cooperation with the U.S. Department of Commerce and private industry, this technology will set automation standards and boost U.S. competitiveness by reducing costs and increasing quality.

From a conservative perspective, the expected annual cost savings for DOE as a result of implementing this technology given the number of samples taken in FY92 are:

- For Organic Sample Analysis - $45 million/year
- For Inorganic Sample Analysis - $15 million/year
- For Analysis of Mixed Waste Samples - $187 million/year

These conclusions were derived as detailed in the calculations below:

For Organic Samples:

(3 million samples in 1992) x (30% organic) x ($300/sample) x (50% done by automation) x (automation costs 1/3 the current cost) = $45M savings if automation were used in 1992 on half the organic samples run by DOE.

For Inorganic Samples:

(3 million samples in 1992) x (45% inorganic) x ($70/sample) x (50% done by automation) x (automation costs are 1/3 current costs) = $15M savings if automation were used in 1992 on half the inorganic samples.

For Mixed Waste Samples:

(3 million samples in 1992) x (25% mixed waste) x ($1500/sample) x (50% done by automation) x (1/3 cost savings) = $187M savings.

Soon the CAA team will put together similar calculations for the DoD and U.S. industry needs. The raw numbers for sample loads and fractions of organic samples, inorganic samples, etc., are archived in the CAA Program files. These numbers were extracted from the cost-benefit analysis developed jointly between the CAA Program team and an industrial partner (Lockheed Martin). The estimates are conservative. For example, the per-sample cost through an organic SAM was estimated to be $15/sample, not 1/3 of $300/sample used in the calculation above. In addition, the CAA team is using the known 1992 sample load. Sample loads are predicted (and observed) to increase to ten times the 1992 level by 1997.

Other direct benefits of the CAA technology include:

- A greater fraction of the remediation budget will be spent on actual cleanup due to the significant decrease in sample analysis cost.
- Faster sample analysis turnaround will allow faster site characterization and cleanup.
- Safety will increase because a faster sample turnaround will allow faster site characterization and more rapid identification of immediate hazards.
- Lower cost of sample analysis will allow more samples to be taken, enabling fuller characterization of sites before cleanup. This results in cheaper cleanup activities (more targeted to better defined contaminants in site maps) and more certain cleanup (lower cost of sample analysis yields less cleanup needed and better validation of cleanup results). Backlogs and holding times will be eliminated.
- Accuracy and precision of each analysis will increase as a result of the automated processing of samples.

Collaboration/Technology Transfer

Information on collaborative and technology transfer efforts of the CAA team is included as a separate task in Section 2.5.

Accomplishments

The CAA team has more than 30 technologies under development or in the planning stages, with 14 SLMs™ developed and undergoing alpha-testing to date. This year, the CAA team has integrated and demonstrated two SAM systems: one for the analysis of semivolatile contaminants in soils and another for the analysis of metals in solid samples. Projected FY96 accomplishments include:

- Beta-Tests of the Mobile semivolatile and 80/80 analysis system
- Various systems, including the new metals analysis system, the new 80/80 system (Concentrator + Sonicator + Gel Permeation SLM™), and the semivolatile SAM (Enhanced PCB)
- New SLMs™
- Soil Sample Preparation SLM™
- Control software program (New Task Sequence Controller [TSC])
- New system user interface
- Sulfur Cleanup SLM™
- Acid Addition SLM™
- Four-station Soxhlet SLM™ (SLM™ modified commercially available instrument)
- High-Volume Concentrator #3 SLM™, including the Ion Exchange Column SLM™; Laser Mass Analyzer Module Time-of-Flight analysis SLM™; Metals Sample Entry SLM™; Perkin/Elmer inductively coupled plasma/atomic emission spectrometer SLM™ (SLM™ modified commercially available instrument); New Training Maintenance Module; Laser-Heated cavity SLM™
- Upgraded Instruments
- Second generation Sonicator SLM™, including the PCB Data Interpretation Module (DIM) (reconfigured), and the Metals System Material Handling System

TTP Information

The Standard Laboratory Module™ and Standard Analysis Method activities are funded under the following technical task plans:

TTP No. RL35C111, "Robotics PNNL Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup"
TTP No. ID15C121, "Robotics INEL Rollup"
TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. AL15C131, "Robotics Technology Development Rollup" at LANL

Contact

Robert M. Hollen
CAA Coordinator
Los Alamos National Laboratory
P.O. Box 1663, MS: J580
Los Alamos, NM 87545
(505) 667-3186
e-mail: hollen@lanl.gov

Bibliography of Key Publications

Hollen, Robert M. and Tracy E. Erkkila. "Integration Of The Environmental Laboratory," *Los Alamos National Laboratory Report* LAUR-94-3704 and *Proceedings from the PittCon Conference*, New Orleans, Louisiana (March 1995).

Hollen, Robert M. "Standardizing The Environmental Chemical Laboratory," *Los Alamos National Laboratory Report* LAUR-94-3772 and *Proceedings from the National American Chemical Society Meeting*, Anaheim, California (April 1995).

Hollen, Robert M. "Progress Toward Automating The Environmental Laboratory," *Los Alamos National Laboratory Report* LAUR-95-350 & 1003 and *Proceedings from the Third International Congress on Environmentally Conscious Design and Manufacturing*, Las Cruces, New Mexico (March 1995).

2.2 AUTOMATED SYSTEM SOFTWARE

TECHNOLOGY NEEDS

A clear need exists for rugged control and interface software to supervise the standardized and modular chemical analysis systems that the CAA Program is currently developing. The Task Sequence Controller (TSC) and associated software under development now within the CAA Program is designed to be a plug-and-play application that will allow seamless integration of the laboratory hardware and software modules developed under the CAA standards. Instrumentation outside of the CAA standards, i.e., noncompliant SLMs™, will also need to be compatible with the TSC so technology from any reliable chemical instrumentation vendor can be integrated into these systems. Tool-kits need to be developed to make development of control drivers for non-compliant instrumentation straightforward.

TECHNOLOGY DESCRIPTION

The goals of this system software development project are to develop a plug-and-play interface specification that allows seamless integration of laboratory hardware and software modules; develop a uniform scripting language to perform chemical analysis methods; and create a data management environment that encompasses sample and equipment event logging, analytical data storage, and an interface to a laboratory-wide information management system to satisfy regulatory and legal requirements.

To achieve these goals, the CAA team is developing software modules that include a TSC, human-computer interface (HCI), and database. The team is also developing specifications for the interfaces between these modules, including a communications library that manages standardized data transmission.

SLMs™ are the plug-and-play building blocks for the automated analytical chemistry laboratory. Each SLM™ is capable of performing a set of chemical or analytical steps that can be combined to form a SAM. A SAM is a programmed sequence or "script" of chemical or analytical operations. The TSC processes these scripts by distributing the sequenced commands to the various SLMs™ so that they can perform their specific operations on each sample. The database stores and provides access to information on the SLMs™ as well as individual samples in order to ensure that detailed records are kept of all processing performed on samples as they pass through the system.

The key to modular chemistry is a standardized interface between laboratory SLMs™ and the TSC. All SLMs™ must conform to a standard interface specification to ensure uniform interaction and controllability. The SLM™ interface defines the communications protocol between the TSC and its attached SLMs™ and is independent of the operations that an individual SLM™ is capable of performing. The fact that the interface protocol is independent of an SLM's™ capabilities is significant, because it allows for plug-and-play functionality. If the interface protocol were to be SLM™-dependent, then any change in the configuration of the automated laboratory would require significant down time to accommodate.

The TSC is modeled after supervisory work-cell controllers developed and used for manufacturing environments. The database module is a distributed data management system that integrates a variety of data storage modalities and presents a single data storage interface to the TSC, SLMs™, and user interface. The HCI provides a graphical user interface to the CAA automated laboratory. The HCI is used to provide a human operator with status information on each SLM™ in the system as well as the position of each sample that is being processed by the system.

BENEFITS

The current state of the art in laboratory automation is the use of "islands of automation." Laboratories often purchase one or two pieces of automated laboratory equipment to address bottlenecks in their analysis processes. Industry focus has been on the analytical instrument that performs the final determination (such as a gas chromatograph), and relatively little attention has been paid to sample preparation and data interpretation. With the modular CAA architecture, analytical laboratories can use automation incrementally and have confidence that their system will be expandable with little or no custom integration work required.

COLLABORATION/TECHNOLOGY TRANSFER

Information on all CAA team collaborative and technology transfer efforts is included as a separate task in Section 2.5.

ACCOMPLISHMENTS

- A standard SLM™ interface protocol was developed for SLM™ control and communications.
- A complete software control system including a TSC, HCI, and database has been developed for use on the commercial-scale demonstration beta test of an organic-PCB SAM and on the alpha test of an inorganic-metals SLM™

- Requirements and specifications have been developed for an enhanced database data manager with a LIMS interface.
- Requirements and specifications have been developed for a methods manager to allow for fully automated method script construction.

TTP Information

Automated System Software efforts are funded under the following TTPs:

TTP No. RL35C111, "Robotics PNNL Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. ID15C121, "Robotics Technology Development Rollup" at INEL
TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. AL15C131, "Robotics Technology Development Rollup" at LANL

Contacts

Robert M. Hollen
CAA Coordinator
Los Alamos National Laboratory
P.O. Box 1663, MS: J580
Los Alamos, NM 87545
(505) 667-3186
e-mail: hollen@lanl.gov

Jerome Chen
CAA Software Functional Leader
Los Alamos National Laboratory
P.O. Box 1663, MS: J580
Los Alamos, NM 87545
(505) 667-9888
e-mail: chen@eldorado.esa.lanl.gov

Bibliography of Key Publications

None at this time.

2.3 AUTOMATED DATA INTERPRETATION MODULE

TECHNOLOGY NEEDS

There are several commercial software techniques applied to data analysis. However, no analytical methods have been developed for routine use in environmental laboratories. In the CAA Program, software technology will be developed for data analysis, and the applications will be tested and validated. The expert system integration of these techniques into routine methods will both enable automation of data analysis and provide a powerful aid to environmental chemists.

TECHNOLOGY DESCRIPTION

The CAA Program is developing laboratory automation in a SLM™ format. A technology objective of the CAA program is to link an automated analytical instrument module (AIM) and automated data interpretation module (DIM) under the SLM™ format. The AIM is the element of the automated laboratory that performs the analysis on an aliquot of the prepared sample. This module will be a commercially available instrument that has been interfaced to the automated laboratory controller. The DIM is a software module in the automated laboratory that delivers chemical knowledge about the sample from the raw data generated by the AIM.

One of the goals of the CAA Program is to link analytical instruments and an automated DIM. The current target for the demonstration of automated analysis and automated data interpretation is EPA Method 8080 for organochlorine compounds and polychlorinated biphenyls (PCBs). A gas chromatography instrument has been incorporated into the automated laboratory, with the DIM exploring the automated interpretation of the chromatograms generated from each sample. Method 8080 is used to detect and quantitate Aroclors. Aroclors is the trade name for the mixtures of PCBs sold commercially. EPA Method 8080 is targeted because chromatographic analysis of environmental samples for Aroclors, fuel spills, and other multicomponent materials are among the most difficult analyses to perform. In addition to gas chromatography, automated data analysis is being developed for mass spectrometry and atomic absorption spectroscopy instruments.

There are several commercial products using pattern recognition techniques applied to data analysis. However, no analytical methods have been developed for routine use in environmental laboratories. In the CAA Program, pattern recognition methods will be developed for data analysis and the applications will be tested and validated. The expert system integration of these techniques into routine methods will both enable automation of data analysis and provide a powerful aid to environmental chemists.

Benefits

Currently, 40 to 60 percent of sample analysis cost is attributed to data interpretation and validation. Facilitating this effort with the automation being developed in the CAA Program will result in significant cost savings in sample analysis. The instrumentation automation being developed in the CAA Program will make the current generation of laboratory testing instruments more robust. These instruments will be able to diagnose samples and instrument problems and take corrective action to ensure that subsequent samples are analyzed successfully. When incorporated into a fully automated laboratory, the DIM will be able to recommend additional sample preparation steps that are necessary to a successful analysis.

Collaboration/Technology Transfer

Information on all CAA Team collaborative and technology transfer efforts is included as a separate task in Section 2.5.

Accomplishments

Data sets for the simultaneous analysis of Aroclors 1242, 1254, and 1260 according to EPA SW 846 Method 8080 were acquired, tested, and calibrated to meet future alpha and commercial-scale demonstration beta test requirements for CAA.

TTP Information

Automated Data Interpretation Module work is funded under the following TTPs:

TTP No. RL35C111, "Robotics PNNL Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. ID15C121, "Robotics Technology Development Rollup" at INEL
TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. AL15C131, "Robotics Technology Development Rollup" at LANL

Contact

Robert M. Hollen
CAA Coordinator
Los Alamos National Laboratory
P.O. Box 1663, MS: J580
Los Alamos, NM 87545
(505) 667-3186
e-mail: hollen@lanl.gov

Leon Klatt
CAA DIM Functional Leader
Oak Ridge National Laboratory
P. O. Box 2008, Bldg. 7601, MS 6306
Oak Ridge, TN 37831-6306
(423) 574-6588
e-mail: lnk@ornl.gov

Bibliography of Key Publications

Klatt, Leon N., John W. Elling, Sue Mniszewski, John Zahrt, and Glen Magelssen. "Validation Studies Of An Expert System Based Automated Data Interpretation: Module For Gas Chromatography," *Proceedings from PittCon* 95 (May 1995).

Klatt, Leon N. "Principal Component Analysis As A Pattern Recognition Technique For Chromatography Data Processing," *Proceedings from at* ICAR, San Diego, CA (January 1996).

Lind, Randall, Leon N. Klatt, and Michael G. Dodson. "Standardization System(S) For The Analysis Of Metals In The Automated Environmental Chemical Laboratory," *Proceedings from the International Conference and Exhibition ... Sample Preparation*, Orlando, FL (January 1996).

2.4 CHEMICAL VALIDATION OF STANDARD LABORATORY MODULES™

TECHNOLOGY NEEDS

Future validation needs include direct interface and planning with the national EPA and several state regulatory offices. This will help ensure that systems are validated in such a way as to be meaningful to these agencies and allow them direct input on design options. A plan will be developed to help understand which regulatory offices should be involved. One estimate of the future need within DOE and DoD is given in the EPA document, *Cleaning Up the Nation's Waste Sites: Markets and Technology Trends*. This document states that as many as 7,000 DoD sites and 4,000 DOE sites may require characterization and cleanup. This technology enhances the analytical processes used to characterize these sites and could result in significant cost savings.

TECHNOLOGY DESCRIPTION

The CAA Program is developing SLMs™ for the automated analysis of trace contaminants in environmental samples. Each of these modules will automate one or more of the methods outlined in the EPA Test Methods for Evaluating Solid Waste (SW 846). Each module developed is scheduled to undergo analytical validation by a validation team. Validation of the individual SLMs™ will verify that:

- Analytical data generated by the automated system are consistent with data generated by manual methods
- Individual SLMs™ are capable of achieving the analytical requirements of trace environmental analysis
- SLMs™ are able to withstand the rigors of automated environmental analysis

Analytical data that must be consistent with manual data includes method detection limits; surrogate recoveries; matrix spike and spike duplicate recoveries; and recoveries of spiked compounds from quality control samples.

To be compatible with trace environmental analysis, automated analytical modules must also meet other requirements such as the ability to handle a diverse range of sample matrices and the ability to generate blank samples free of undesirable contaminants. Finally, in order to be used in an environmental laboratory, other problems such as software and hardware stability, ease of use, maintenance, and sample throughput must be evaluated before the final production of prototype SLMs™ are ready for commercial use.

In order to evaluate the criteria outlined above, the Organic Analysis Group validation team designed a series of tests that are consistent with the requirements for analytical methods currently in use. These tests include method blank contamination and cross-contamination evaluations, a method detection limit evaluation, analysis of quality control samples, and analysis of "real" environmental samples. These tests provide information on the overall performance of the automated system. Various matrices ranging from blank materials to silty environmental samples have been used to evaluate the performance of the SLMs™ in terms of the adequacy of the data generated, mean time between failures, and mode of failure.

Benefits

During the integration and testing of the organic system, over 52 samples were processed during a four-day period using approximately 12 hours of technician time to prepare the samples for automated operations. Precision data was slightly better using this automated system than the data available from manual operations. These numbers are expected to improve with the modifications to the high-volume concentrator (HVC) that were completed following the integration test.

Up to 30 samples per day can be processed through the integrated organic system using three hours of technician time spread over two shifts. This rate is currently limited by the configuration of the racks that hold samples and containers, and could be improved with modifications to this ancillary equipment.

Collaboration/Technology Transfer

During the validation of each of the SLM™ modules, the validation team is collaborating with the CAA Program design engineering teams responsible for the fabrication of the specific SLMs™. Innovations and suggestions developed within the validation team are communicated to the entire CAA Program.

The CAA Program is currently interested in CRADAs and contracts with third-party laboratories qualified to perform chemical and design validation. This third-party validation will involve commercial-scale demonstration beta testing of SLM™ technology and provide third-party feedback with a variety of sample data.

Accomplishments

An integrated system consisting of two Soxhlet SLMs™, an HVC, and a gas chromatograph was tested. The system processed samples consisting of blanks, spiked blanks, quality control samples, and environmental samples from a Los Alamos waste site. The surrogate recoveries for these samples were within the control limits of the Organic Analysis Group's control limits. Modifications to the HVC have been completed in order to obtain improved surrogate and analyte recovery.

TTP Information

Chemical Validation of Standard Laboratory Modules™ is funded under these TTPs:

TTP No. RL35C111, "Robotics PNNL Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. ID15C121, "Robotics Technology Development Rollup" at INEL
TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. AL15C131, "Robotics Technology Development Rollup" at LANL

Contacts

Robert M. Hollen
CAA Coordinator
Los Alamos National Laboratory
P.O. Box 1663, MS: J580
Los Alamos, NM 87545
(505) 667-3186
e-mail: hollen@lanl.gov

Matthew Monagle
CAA Chemical Validation
Los Alamos National Laboratory
P.O. Box 1663, MS: E548
Los Alamos, NM 87545
(505) 665-7422
e-mail: monagle@lanl.gov

Bibliography of Key Publications

Monagle, Matthew, and Robert Johnson. "Single-Laboratory Validation of an Automated Sonication System", *Los Alamos National Laboratory Report* LAUR-94-3220.

Monagle, Matthew, and Robert Johnson. "Integration Of Sample Analysis Method For Polychlorinated Biphenyls" Los Alamos National Laboratory report LAUR 96-492 and *Proceedings of the International Conference and Exhibition . . . Sample Preparation*, Orlando, FL (January 1996).

2.5 TECHNOLOGY TRANSFER IN THE CAA PROJECT

TECHNOLOGY NEEDS

The need for both the products and standards offered by SciBus Analytical, Inc. is well documented. Within the lab, costs have skyrocketed, while competition has increased, forcing price erosion and margin depletion. Labor pools have diminished, with labor costs escalating. Labor safety is also an issue, as is the general legal defensibility of all chemical analyses, especially in product liability, environmental studies, and pharmaceutical development. Data interpretation and report generation require twice as much direct cost than the actual analysis of the chemical sample. For equipment manufacturers, the SciBus standards offer design consistency, manufacturing cost reductions, increased utility of products, and enhanced market opportunities. This would include opportunities for both large and small equipment manufacturers.

Government and industry face similar problems with respect to characterizing and remediating sites potentially contaminated with radioactive and hazardous wastes. The first step in cleaning up sites is to determine if they are contaminated, and if they are, characterizing the contaminants. Currently, DOE and its contract laboratories perform about four million determinations each year. DOE estimates that in 1997 analysis requirements will reach approximately 10 million determinations per year. This work is tedious, repetitive, and although prescripted by regulatory guidelines such as EPA's SW846 method compendium, prone to chemist variation and error.

TECHNOLOGY DESCRIPTION

To meet the environmental restoration and waste management goals of government and industry, several government laboratories, universities, and private companies have formed the CAA team. The goal of this consortium is to design and fabricate automated systems that standardize the hardware and software of the most common chemical analysis methods. In essence, the CAA team takes the conventional, regulatory-approved (EPA Methods) manual chemical analysis processes and automates them. The automation consists of SLMs™ that perform the work in a much more efficient, accurate, and cost-effective manner.

The current laboratory automation paradigm consists of limited capability islands-of-automation that do not integrate into a systems architecture to provide an analysis path about the remediation effort. Today, the chemist must perform most aspects of sample analysis manually. By designing and transferring to industry partners systems that are based upon the SAM architecture, the group is working towards a standardized and modular system that provides a plug-and-play approach to laboratory automation. SAMs are integrated systems comprised of standardized instruments, known as SLMs™, that automate a portion of an environmental method.

In order to have the developed products available for commercial use, the CAA program required a technology-transfer partner from the commercial marketplace. SciBus Analytical, Inc. was chosen by DOE for this purpose. SciBus Analytical, Inc. is committed to introducing a new paradigm of SLMs™ that automate many of the complex, time-consuming, labor intensive, and rework-prone tasks found in today's industrial and commercial chemistry labs. This new paradigm involves both hardware and software for sample preparation and chemical data interpretation/data management. Every product offered by SciBus utilizes a standard interface, command and communication specification, and allows complete interchangeability - true plug-and-play capability - for all equipment and software developed to this standard.

To date, DOE and the five National Laboratories involved in the CAA program have invested about $20 million into the development of these new technologies. The CAA Program stands to benefit from a committed $48 million of continued in-kind support and product development from SciBus Analytical, Inc. over the next five years of the CRADA. The CAA Program has also involved some of the leading analytical equipment manufacturers and laboratories from the industrial and commercial markets - 3M, Hewlett-Packard, Varian, ABC Equipment, Raytheon/E-Systems, and Thru-Put Systems, as well as four university research teams.

SciBus Analytical, Inc. was chosen to be the exclusive recipient of all CAA technology for the purposes of global commercialization and was chosen over significant competitors. To that end, SciBus has embarked on an international program to license all CAA-developed hardware and initiate an international standards organization to execute the CAA-developed design parameters. SciBus has also initiated its own in-house development and marketing team to produce and sell laboratory software tools to the 176,000 analytical laboratories worldwide, starting with the 28,500 U.S.-based labs that encompass such market segments as petroleum products, food and beverage, cosmetics, pharmaceuticals, bioengineering, petro-chemicals, cellulose/plastics, environmental labs, and specialty materials research.

Benefits

Direct benefits of CAA technology include:

- A greater fraction of the remediation budget to be spent on actual cleanup due to the significant decrease in sample analysis cost
- Faster site characterization and cleanup will result from faster sample analysis turnaround

- Increased safety because a faster sample turnaround allows faster site characterization and rapid identification of immediate hazards
- Lower sample analysis costs allows more samples to be taken, enabling fuller characterization of sites before cleanup. This results in cheaper cleanup activities (targeted to better defined contaminants in site maps) and more certain cleanup (lower cost of sample analysis yields less cleanup needed and better validation of cleanup results). In addition, backlogs and holding times will be eliminated
- Increased accuracy and precision of each analysis is a result of the automated sample processing

Collaboration/Technology Transfer

In collaboration with SciBus Analytical, Inc. of Sunnyvale, California, as well as various industrial partners, the DOE National Laboratories have created the CAA Program to develop automation tools, both hardware and software, which will position the analytical chemistry market for true plug-and-play automated compatibility.

Accomplishments

- The Mobile Environmental Laboratory (MEL), shown in Figure 2.5-1, was built and demonstrated at the DOE Robotics Forum in Albuquerque held in August 1995.
- In February 1996, a joint multi-laboratory CRADA was executed between INEL, LANL, ORNL, PNNL, SNL and SciBus Analytical, Inc.
- In February 1996, a unique joint exclusive licensing agreement was completed between all the national labs and SciBus Analytical, Inc. This licensing agreement is a first-of-a-kind for the DOE in that all participating labs share equally in the royalties,

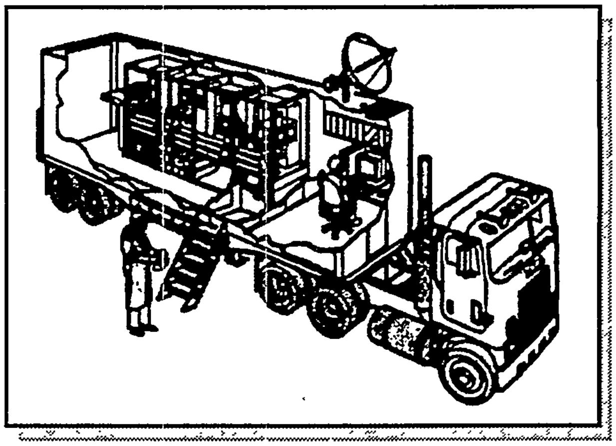


Figure 2.5-1. Rather than collect and transport samples that may contain hazardous contaminants, the CAA team has developed each system so that it fits aboard an 18-wheeled truck. The truck contains all the necessary equipment, including the collection, analysis, and data interpretation modules. CAA can custom build systems to suit customer needs - the system need not be mobile.

and marks a new and more beneficial methodology to ensure technology transfer success and commercialization.

TTP Information

Technology Transfer in the CAA Project is funded under the following TTPs:

TTP No. RL35C111, "Robotics PNNL Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. ID15C121, "Robotics Technology Development Rollup" at INEL
TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. AL15C131, "Robotics Technology Development Rollup" at LANL

Contact

Robert M. Hollen
CAA Coordinator
Los Alamos National Laboratory
P.O. Box 1663, MS: J580
Los Alamos, NM 87545
(505) 667-3186
e-mail: hollen@lanl.gov

John F.S. Condren
CEO and Chairman
SciBus Analytical, Inc.
155 Moffett Park Drive, Suite 210
Sunnyvale, CA 94089
(408) 734-0400
e-mail: condren@esa.lanl.gov

Bibliography of Key Publications

Hollen, Robert M. "Robotic Automation of the Environmental Chemical Laboratory," *Los Alamos National Laboratory Report* LAUR 94-930 (August 1994).

Hollen, Robert M. "Commercialization Opportunities in the Contaminant Analysis Automation Program," *Proceedings from the Site Characterization Meeting (Innovative Technology & Technology Transfer)*, Washington, D.C. (September 1994).

Hollen, Robert M. "Progress Toward Automating the Environmental Laboratory," *Proceedings from the ACS Special Topics Symposium on Emerging Technologies in Hazardous Waste Environments VI*, Atlanta, GA (September 1994).

Hollen, Robert M. "Progress In Standardizing And Automating The Environmental Analytical Laboratory", *International Symposium On Laboratory Automation And Robotics*, Boston, MA (October 1994).

Hollen, Robert M. and Octavio Ramos. "Contaminant Analysis Automation, An Overview," *Los Alamos National Laboratory Report* LAUR-96-732 and *Proceedings from the 1996 New Mexico Conference on the Environment*, Albuquerque, NM (March 1996).

3.0 ROBOTICS DECONTAMINATION AND DISMANTLEMENT (D&D)

There are a large number of contaminated facilities including hot cells, canyons, glove boxes, and reactor facilities at DOE sites that must eventually undergo some form of decontamination and dismantlement (D&D). As facilities transition from operational use, they will be deactivated and prepared for continuing surveillance and maintenance. Deactivation and surveillance and maintenance activities pose many of the problems that will need to be addressed in ultimate D&D; emphasis is placed on characterization, data capture, and selective D&D in order to define and minimize risk and costs associated with possible long-term Surveillance and Maintenance status.

The overall emphasis of the RTDP D&D application area focuses on systems and capabilities that can be used in facility deactivation and on-going Surveillance and Maintenance activities with extended application to final facility D&D tasks. Major thrusts for D&D are (1) Surveillance and Maintenance risk and cost reduction evaluation methodologies; (2) characterization, mapping, and inspection system; (3) selective equipment removal system (SERS); (4) full-scale testing; (5) Houdini debris removal system; and (6) D&D programmatic coordination. The RTDP D&D team is composed of Oak Ridge National Laboratory (ORNL), Sandia National Laboratories (SNL), Idaho National Engineering Laboratory (INEL), Savannah River Technology Center (SRTC), Pacific Northwest National Laboratory (PNNL), and Fernald. The RTDP D&D application area coordinator also directs D&D related task activities funded separately under the University Robotics Program at the University of Texas at Austin, the University of Michigan, and the University of Florida. The RTDP D&D activities directly support the D&D Focus Area. An overview of each major thrust area is given below.

Surveillance and Maintenance Risk and Cost Reduction Evaluation Methodologies:

The objective of this project is to provide systematic, risk-based relative comparisons of competing alternatives associated with the use of robotic systems in reducing facility surveillance and maintenance costs. As a result of this work, a methodology and software tool, DECIDE (DECIsion, Definition, and Evaluation), was developed under an industry contract that not only accomplishes all of the original goals for this project, but also has a much wider application to risk-based decision making. In FY96, this methodology will be applied to the Argonne National Laboratory (ANL) CP-5 reactor dismantlement project. The benefits of the methodology are that it formalizes the decision process for assessing alternatives, standardizes the decision-making process, and provides documentation for justifying decisions. The software provides a valuable tool for evaluating the viability of remote systems application to D&D tasks.

Automated floor characterization offers several potential benefits including cost reduction, improved data quality, automated data storage and record keeping, and simultaneous operation of multiple sensors.

Characterization, Mapping, and Inspection Systems:

This major thrust contains four major activities for FY96: (1) completion of integration and demonstration of a floor characterization system, mobile automated characterization system (MACS), initiated in FY95 including a reduced access characterization subsystem (RACS); (2) completion, demonstration, and transfer to industry of the small pipe characterization system (SPCS); (3) demonstration of the internal duct characterization system (IDCS) developed in FY95; and (4) the initiation of the development of a mobile prototype mapping system to evaluate the feasibility of robot vehicle-based automated facility and equipment mapping. The automated facility/equipment mapping system will provide the means to remotely assess the physical state of contaminated facilities with little or no worker exposure. The resulting facility and equipment data will be valuable in planning subsequent D&D activities. Such data also enhances the operational efficiency of additional remotely operated or automated D&D systems.

Selective Equipment Removal System (SERS):

The primary activity under this major thrust is the insertion of RTDP technology into the CP-5 reactor dismantlement activities conducted under the D&D Focus Area Large-Scale Demonstration Program. This major thrust contains four primary activities for FY96: (1) continued development and evaluation of SERS operator interface and controls capabilities including task space scene analysis and supervisory control; (2) installation of swing-free crane control at the ANL CP-5 reactor dismantlement site and evaluation of crane-based deployment of the dual-arm work module (DAWM); (3) procurement checkout and delivery of a DAWM for the CP-5 reactor dismantlement task; and (4) tooling development including multi-modal tool stand-off control and specialized tooling and support systems for the CP-5 reactor dismantlement. SERS provides the capability to demonstrate and evaluate a mobile telerobotic system suitable for performing selective decontamination and dismantling functions applicable to pre-surveillance and maintenance facility preparations and eventual D&D operations. An overhead transporter and vehicle-based deployment of the dual-arm manipulation system provide the two primary mobility options for operation in pre-surveillance and maintenance and eventual D&D telerobotic decontamination and dismantlement tasks. Remotely deployable telerobotic systems remove workers from direct exposure to contaminants and industrial hazards. For pre- or on-going surveillance and maintenance activities, telerobotic systems can be deployed for selective decontamination or dismantlement to eliminate high-risk or high-surveillance and maintenance cost contaminants or equipment.

Full-Scale Testing:

The Robotics Technology Assessment Facility (RTAF) was established in FY95 at ORNL to provide an experimental facility capable of supporting full-scale testing. In FY96, the RTAF will be used to support full-scale testing of dismantlement scenarios for the CP-5 reactor at ANL. Full-scale CP-5 mockups will be installed in the RTAF. Test preparations will be completed based on dismantlement scenarios, and demonstrations will be performed under realistic operational conditions. This full-scale testing will provide cold testing and training opportunities that are critical to successful field deployment of remote systems. Full-scale test and evaluation performed in the D&D RTAF allows realistic evaluation of candidate robotic D&D technologies. For specific D&D tasks, the use of full-scale mockups in the RTAF provides cold testing and training prior to actual deployment of a remote system within the actual D&D activities. By making the RTAF capabilities available for DOE sites, industry, and university use, overall test and evaluation costs for candidate systems will be reduced by minimizing the need for duplicate test facilities, analysis capabilities, and mockup modules.

Houdini Debris Removal System:

The Position and Orientation Tracking System (POTS) developed and demonstrated in FY95 will be modified for field use and integrated with the Houdini vehicle. The second RTDP addition to the Houdini system is a graphical user interface to display the position and orientation data provided by POTS. This interface will be developed in collaboration with RedZone Robotics, Inc., via a CRADA. The benefits of the POTS and user interface additions to the Houdini system will be improved telepresence for the operators. Many D&D environments, including typical tank environments, lack sufficient features in the debris, floor, and walls to allow easy recognition of position and orientation. Operator efficiency will be greatly improved with these two enhancements.

CONTACT

Dennis C. Haley
D&D Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, TN 37831-6304
(423) 574-5691
e-mail: haleydc@ornl.gov

3.1 SURVEILLANCE AND MAINTENANCE RISK AND COST REDUCTION EVALUATION METHODOLOGIES

TECHNOLOGY NEEDS

A methodology is needed to assist in evaluating the level of activities being performed during facility deactivation and ongoing surveillance and maintenance to properly address the combination of risk and cost associated with various activity scenarios. As part of those activities, use of robotic or remote systems needs to be properly represented to understand the true potential impact and payoff. The development cost, operational cost during deactivation and surveillance and maintenance, and the potential for ultimate use during final D&D are parameters that are included in evaluations relative to the use of robotic and remote systems for these tasks.

TECHNOLOGY DESCRIPTION

The surveillance and maintenance Risk and Cost Reduction Evaluation Methodologies activity provides the development of analysis tools for the evaluation of risk and cost/benefit tradeoffs associated with the use of robotic systems for surveillance and maintenance and deactivation work. This task supports working with a vendor to develop a commercially available application illustrated by Figure 3.1-1, useful for the evaluation of robotic systems

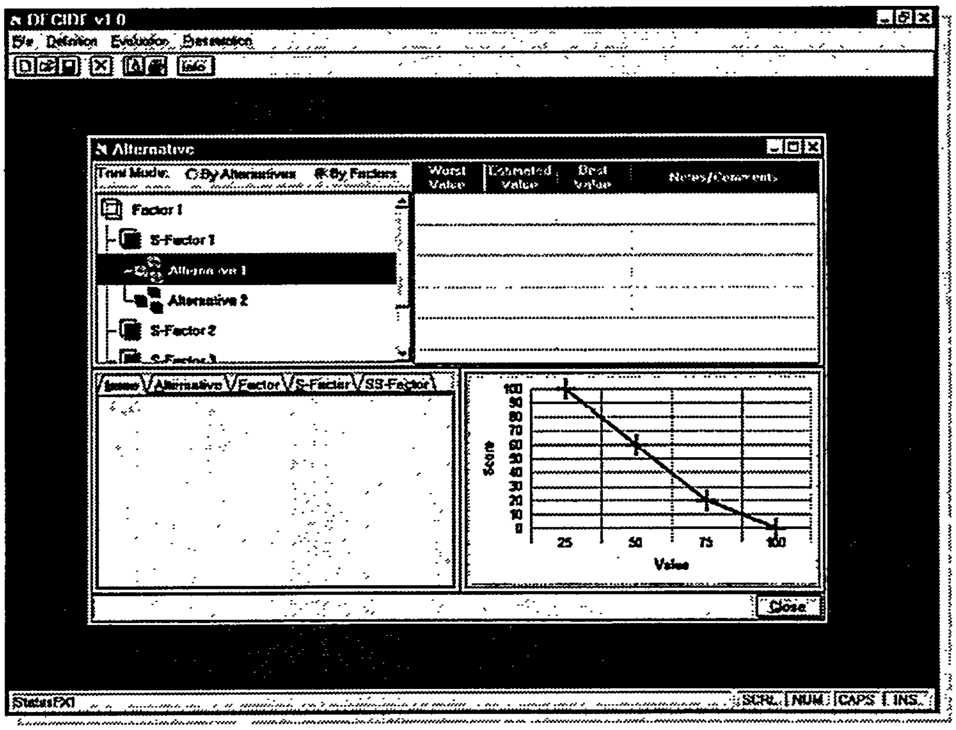


Figure 3.1-1. Comparison of weighted scores for alternatives.

during the facility deactivation and continuing surveillance and maintenance. To accomplish this task, assessment of methodologies will be performed and a final strategy will be selected for use in candidate facilities to test and refine the methodology.

BENEFITS

This methodology will provide a fairer representation of the impact of robotic technology for facility surveillance and maintenance and D&D. It will account more appropriately for costs and risks that have not been factored into the analyses in the past. In addition, the methodology will assist in the direction of research and development for surveillance and maintenance and D&D.

COLLABORATION/TECHNOLOGY TRANSFER

This technology is being jointly developed by ORNL, SRTC, SNL, INEL, and JBF Associates, Inc.

ACCOMPLISHMENTS

- Through collaboration with JBF Associates, Inc., existing risk analysis methods were surveyed, the best-suited approaches were determined, and a prototype computer code was written that served as an analysis tool for implementing the methodology.
- The methodology was demonstrated at INEL on September 7-8, 1994. The demonstration goal was to remove dirt and loose material from the offgas cell floor at a waste calcining facility. The preferred cleanup option was found to be remote liquid decontamination.
- The JBF Associates, Inc., DECIDE software is now commercially available as part of a training course on risk and cost-benefit analysis.

TTP INFORMATION

Surveillance and Maintenance Risk and Cost Reduction Evaluation Methodologies work is funded under the following TTPs:

TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. SR16C151, "Robotics SRTC Rollup"
TTP No. ID75C121, "Robotics INEL Rollup"

CONTACTS

Dennis C. Haley
D&D Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, TN 37831-6304
(423) 574-5691
e-mail: haleydc@ornl.gov

Randy Singer
Surveillance and Maintenance
Project Coordinator
Savannah River Technology Center,
Building 773-A
Aiken, SC 29808
(803) 725-2407
e-mail: randy singer@srs.gov

BIBLIOGRAPHY OF KEY PUBLICATION

Guthrie, Vernon H., and David A. Walker. *Risk-Based Robotic Planning: Phase I - Methodology Development*, JBF Associates, Inc., Document No. JBFA-235-94. Knoxville, Tennessee (1994).

Haire, M. J., Vernon Guthrie, and David A. Walker. "Practical Risk-Based Decision Making: Good Decisions Made Efficiently", presented at the 1995 ASME *International Mechanical Engineering Congress and Exhibition*, San Francisco, California (November 1995).

3.2 CHARACTERIZATION, MAPPING, AND INSPECTION SYSTEM

TECHNOLOGY NEEDS

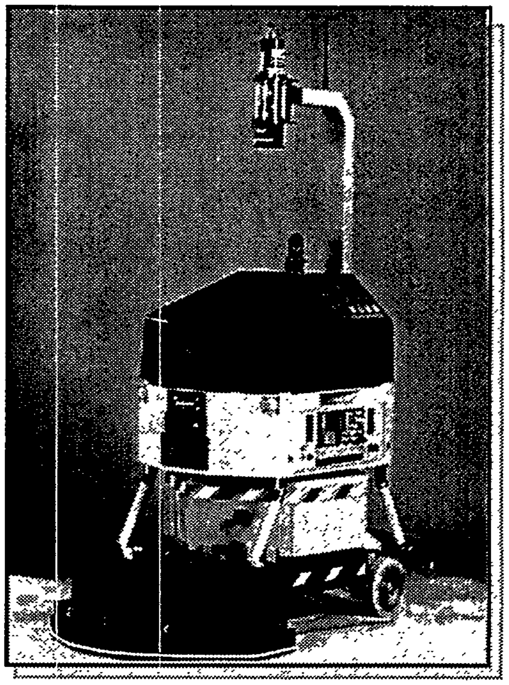


Figure 3.2-1 Mobile Automated Characterization System (MACS).

In order to define the condition of the facility and minimize the risk and costs associated with possible long-term surveillance and maintenance, activities required prior to final D&D facility deactivation and surveillance and maintenance activities place emphasis on characterization and data capture. Physical and contaminant characterization of a facility in question can be performed manually or with remote or robotic system assistance. Data generated from these activities must be captured in a form that is readily usable for visualization of the facility, equipment, and possible contaminants. The data will also provide input for control purposes to remote or robotic systems to be used during deactivation, surveillance and maintenance, or final D&D. Such a system can also provide a long-term record of facility configuration and condition as deactivation, surveillance and maintenance, or D&D activities take place.

A system to perform floor characterization needs to be developed for the hundreds of acres of floor space at DOE facilities that require characterization and ultimate decontamination. The floors must be characterized before, during, and after any decontamination activities. Floor characterization of these huge areas by manual methods is slow, prone to error, and generates excessive secondary waste from worker protective clothing. Mobile robotic systems are faster, produce more reliable, repeatable data, and reduce waste and personnel exposure.

TECHNOLOGY DESCRIPTION

The Characterization, Mapping, and Inspection System activity provides for the development and demonstration of multi-purpose mobile robotic systems for contaminant characterization, facility mapping, and inspection functions associated with facility surveillance and maintenance. The Mobile Automated

Characterization Systems (MACS) is shown in Figure 3.2-1. Development will begin with hierarchical data acquisition, data management, and data display for three-dimensional facility mapping, contaminant mapping and record keeping, as well as contamination/configuration tracking. A mobile robotic system will initially perform floor characterization using radiation sensors to accumulate contaminant information for the initial data for the facility mapping system. The facility mapping system will provide the capability to capture facility geometry data upon which contaminant data may be mapped. Facility mapping captures characterization data and identifies candidate areas for selective D&D that can then be evaluated relative to minimizing ongoing surveillance and maintenance risks and costs. As activities occur, the facility map can be updated to reflect current conditions and to maintain facility configuration information for eventual D&D activity planning, control, and monitoring, shown by Figures 3.2-2 and 3.2-3. This task will interact and incorporate mapping technologies developed through DOE/EM, OST-funded Program Research and Development Announcement (PRDA) con-

Figure 3.2-2 Sample composite computer model of chemical process equipment.

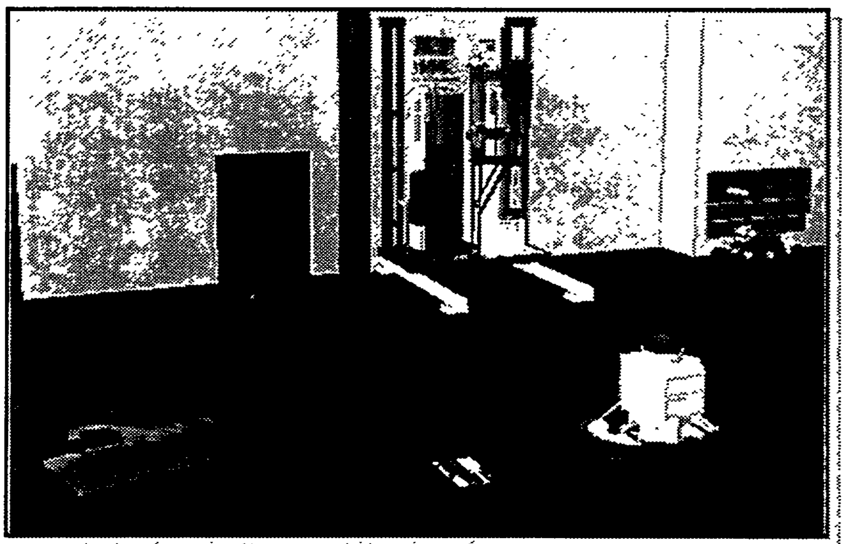


Figure 3.2-3. Sample composite computer model of a facility with several simulated characterization efforts underway.

tracts with Mechanical Technology, Inc., and Coleman Research, as well as University research funded through the Nuclear Engineering program.

Benefits

Automated floor characterization offers the following advantages:

- Cost reduction with simultaneous and round-the-clock operations
- Data quality enhancement through improved scan rate control
- Precise recordkeeping through automated data collection and storage
- Survey data comparisons not feasible by manual methods
- Elimination of tedious tasks

Mobile Mapping System offers the following capabilities:

- Remote 3-D characterization of large facility areas
- Geometric modeling of raw sensor data
- Creation of a 3-D database suitable for addition of spatially tagged contamination data

Collaboration/Technology Transfer

This technology is being jointly developed by ORNL, Savannah River Technology Center (SRTC), INEL, and SNL. It will include industry interactions with Mechanical Technology, Inc., Coleman Research, University of Florida, University of Tennessee, University of Michigan, and University of Texas.

Accomplishments

This activity was initiated in FY94. Past accomplishments and future plans include:

- Requirements and conceptual design were developed for the facility mapping system during the first half of FY94.
- Capabilities developed by industry (primarily under DOE PRDA contracts) were evaluated for completeness and functionality. Additional functions were prototyped to provide an initial system capability for demonstration in the fourth quarter of FY94. This demonstration was given to an audience consisting of the D&D National Coordinator and reviewers from the National Academy of Sciences.

- Process Systems high bay was completed using a photogrammetric technique. This mapping effort was used to establish a baseline for commercially available in terms of cost, time, and accuracy. Future mobile robotics mapping activities will be compared to this effort.
- Specifications for a floor characterization system (based on previous work at SRTC) and requirements determined for use of the system in the Oak Ridge K-25 Site process buildings were established and completed in early FY95.
- An industry procurement for the floor characterization system was placed during the third quarter of FY94. System integration and testing of the floor characterization system for radiological contamination sensing was performed in the second quarter of FY95.
- In the second quarter of FY95, a contract was placed for the purchase of a mobile mapper vehicle to be used as a prototype 3-D spatial mapper. FY96 plans include mounting a laser radar, structured light system, and several video cameras on the mobile mapper platform for use in evaluating mobile mapping capabilities.
- In FY96, increased automation capabilities and a subsystem for enhanced access of restricted spaces will be added to the floor characterization system.
- In the fourth quarter of FY96, a demonstration of mobile mapping capabilities will be given to the DOE and D&D communities by the RTDP. This demonstration will include mobile vehicle performance, sensor performance, and data modeling capabilities.

TTP INFORMATION

Characterization, Mapping, and Inspection System activities are funded under the following TTPs:

TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. SR16C151, "Robotics SRTC Rollup"
TTP No. ID75C121, "Robotics INEL Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL

Contact

Dennis C. Haley
D&D Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, TN 37831-6304
(615) 574-5691
e-mail: haleydc@ornl.gov

Bibliography of Key Publications

Richardson, B.S., A.M. Dudar, C.R. Ward, and D.C. Haley. "A Mobile Automated Characterization System (MACS) for Indoor Floor Characterization," presented at the ANS *6th Topical Meeting on Robotics and Remote Systems*, Monterey, California (1995).

Dudar, A.M., D. Wagner, and G. Teese. "A Mobile Autonomous Robot for Radiological Surveys," *Proceedings, 40th Conference on Remote Systems Technology*, Volume 2 (1992).

Harrigan, R. W. "Intelligence to Conventional Industrial Robots," ANS, Knoxville, Tennessee, pp. 619-624 (1994).

Barry, R.E, B.L. Burks, and C.Q. Little. "Requirements and Design Concept for a Facility Mapping System," presented at the ANS *6th Topical Meeting on Robotics and Remote Systems*, Monterey, California (1995).

Anderson, M.O., M. D. McKay, and B. S. Richardson. "Multirobot Automated Indoor Floor Characterization Team," (1995).

3.3 SELECTIVE EQUIPMENT REMOVAL SYSTEM

TECHNOLOGY NEEDS

Hazards associated with contaminated hot cells, canyons, glove boxes, and reactor facilities at DOE sites are radiation, radiological contamination of the equipment being removed, and hazardous chemicals associated with the processes performed at the facilities. Because of these hazards, deactivation, surveillance and maintenance, and ultimate D&D will have to be performed remotely. D&D operations include disassembly of process equipment, cutting pipes, size reduction of equipment to be removed, transport of pipe and equipment out of the facilities, decontamination of equipment before removal from a facility, and decontamination of floors, walls, and remaining equipment in facilities to be refurbished. Robotics may also be needed to dismantle the facility structure. Hardened robotic systems for facility D&D can provide capabilities to accomplish these operations safely with workers away from the work site. Facility deactivation activities place emphasis on selective D&D in order to minimize the risk and costs associated with potentially long-term surveillance and maintenance activities and final D&D. For pre-surveillance and maintenance facility preparations, or ongoing surveillance and maintenance activities, a remote system capable of being deployed for selective D&D can eliminate high risk or high surveillance and maintenance cost contaminants or equipment.

TECHNOLOGY DESCRIPTION

The Selective Equipment Removal System (SERS) has been developed to demonstrate and evaluate a mobile telerobotic system suitable for performing selective D&D functions applicable to pre-surveillance and maintenance facility preparations. The SERS uses a reconfigurable dual-arm work module (DAWM) to demonstrate inspection, decontamination, and equipment removal operations. DAWM has been deployed from an overhead transporter for initial SERS demonstrations as shown in Figure 3.3-1. Evaluations will be performed in FY96 for the development of a mobile work system, shown in Figure 3.2-2, through interaction with the OST-funded PRDA contract with Carnegie Mellon University/RedZone Robotics, Inc. SERS tasks have included development of operator control console capabilities, development of scene generation and analysis capabilities, and a study of a remote tool set.

BENEFITS

Development of SERS will afford the opportunity to demonstrate and evaluate a mobile telerobotic system suitable for performing selective D&D functions applicable to pre-surveillance and maintenance facility preparations. Overhead transporter, overhead crane, and vehicle-based deployment of the DAWM system provide the mobility options for SERS operation in pre-surveillance and maintenance and eventual D&D telerobotic tasks. Remotely deployable telerobotic systems remove workers from direct exposure to contaminants and industrial hazards.

Collaboration/Technology Transfer

This technology is being jointly developed by ORNL, SNL, and INEL and entails interaction with the University of Tennessee and Carnegie Mellon University.

Accomplishments

Initial SERS subsystem fabrication, modification, and integration has been completed. Specific subsystems include a DAWM, deployment from an overhead transporter, operator control console, task space scene analysis system, and high and low-level control system capabilities required to provide teleoperation, telerobotic operation, and robotic operation. The overhead transporter deployed SERS began task demonstration in the fourth quarter of FY94 at ORNL. Human-machine interfaces and automation enhancements will be developed to support various modes of mobile deployment.

- For FY95, Carnegie Mellon University/RedZone Robotics, Inc., delivered their SERS/DAWM mobile platform deployment option "Rosie" vehicle, developed under a DOE METC PRDA. Testing began in the Robotics Technology Assessment Facility at ORNL.
- Future direction indicates deployment of both Rosie and the DAWM in the dismantlement of the CP-5 research reactor at Argonne National Laboratory.

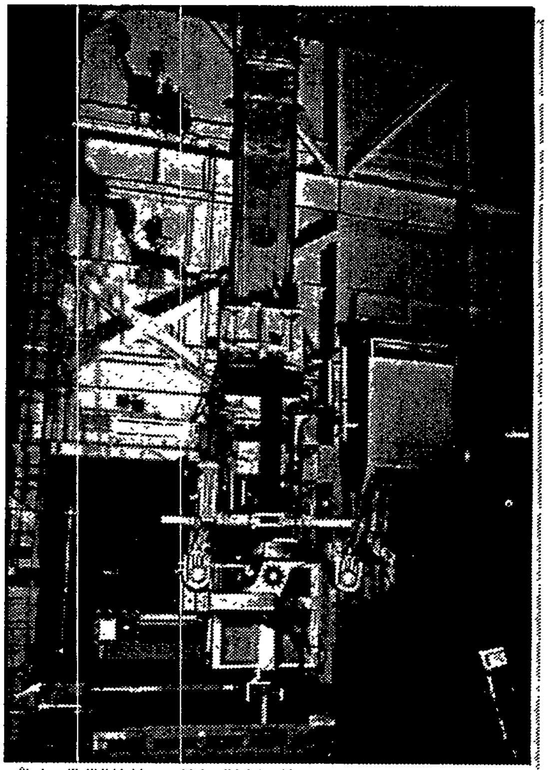


Figure 3.3-1. DAWM (in lower third of picture) on Overhead Transporter

TTP Information

The Selective Equipment Removal System is funded under the following TTPs:

TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. ID75C121, "Robotics INEL Rollup"

Contact

Dennis C. Haley
D&D Coordinator
Oak Ridge National Laboratory
P.O. Box 2008,
Building 7601
Oak Ridge, TN 37831-6304
(615) 574-5691
e-mail:haleydc@ornl.gov

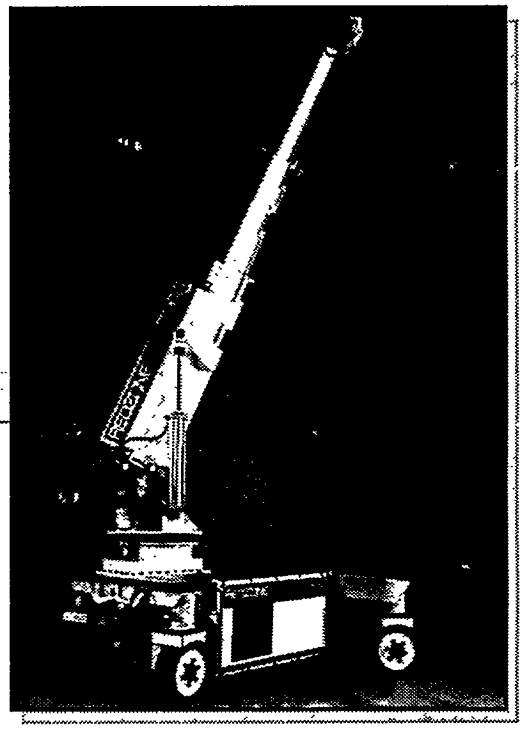


Figure 3.3-2. CMU/RedZone Mobile Vehicle Deployment Option.

Bibliography of Key Publications

Noales, M.W., W.R. Hamel, and W.E. Dixon. "Application of a Selective Equipment Removal System to D&D Tasks," presented at the ANS 6th Topical Meeting on Robotics and Remote Systems, Monterey, California (1995).

3.4 SMALL PIPE CHARACTERIZATION SYSTEM

TECHNOLOGY NEEDS

Across the DOE complex, there are numerous facilities identified for D&D with piping that have been placed on the contaminated list because of internal contamination risk. Much of this piping is inaccessible because it is buried, embedded in concrete, or runs through hot cells. Identification and mapping of contaminants in piping is a major concern during facility deactivation. An understanding of the types of contaminants present and the extent of contamination are primary drivers for decisions regarding decontamination and/or dismantlement, all of which affect initial deactivation cost, ongoing surveillance and maintenance risk and cost, and eventual D&D strategy and cost. Currently there are no robotic/remote systems capable of characterizing pipe in the two- to three-inch size range. Characterization of this piping is essential before, during, and after D&D activities. Identifying those sections of the piping that are actually contaminated can greatly reduce the amount of material sent to waste handling facilities and/or the amount of secondary waste generated performing unneeded decontamination.

TECHNOLOGY DESCRIPTION

The Small Pipe Characterization System (SPCS) activity provides for the design, procurement, fabrication, integration, demonstration, and technology transfer of a system for characterizing contaminants in pipes with internal diameters between two and three inches. The SPCS, shown in Figures 3.4-1 and 3.4-2, consists of a control computer, a tether for data communication, and a pipe crawling vehicle. The pipe crawler is driven by DC-motor-powered wheels arranged in a triangular configuration and sprung against the sides of the pipe for traction. The configuration of the wheels allows the pipe crawler to maneuver through radiused elbows and to adapt to changing pipe diameters "on the fly." Live color video is transmitted from the camera on the front of the pipe crawler to the control computer. The SPCS is also capable of deploying small sensors such as radiation detectors; however, appropriately sized sensors have not yet been developed.

BENEFITS

This technology makes it possible to characterize previously inaccessible piping. Determining the absence or presence of contamination and the extent of contamination in piping will reduce the costs of D&D activities by treating only the affected areas. It also reduces the amount of generated secondary waste from uncontaminated piping. Personnel exposure can then be limited only to areas with uncontaminated piping.

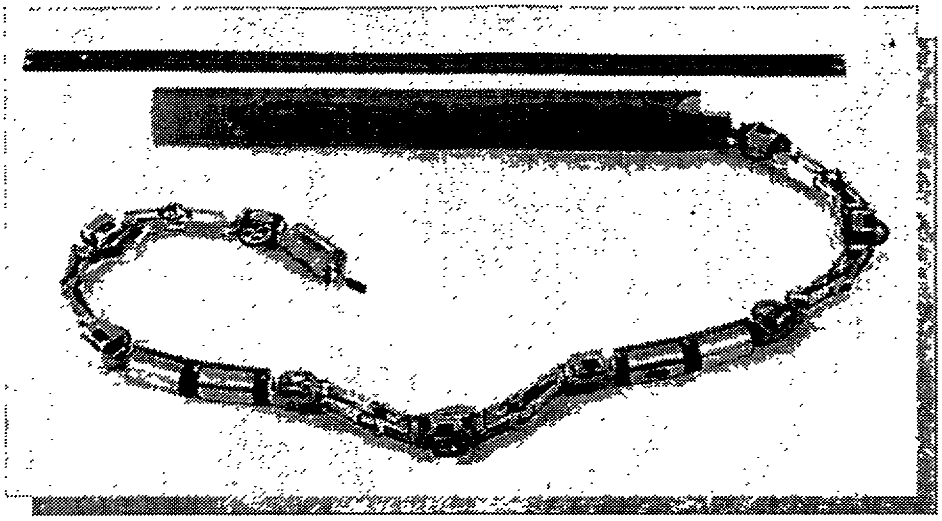


Figure 3.4-1. Close-up of Front Section of SPCS Vehicle.

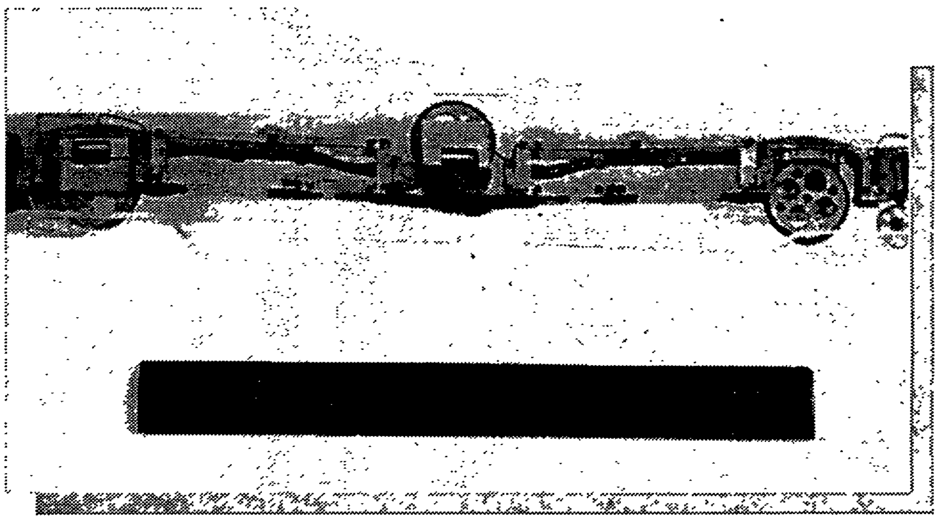


Figure 3.4-2. SPCS Inserted Into 2-Inch Pipe.

COLLABORATION/TECHNOLOGY TRANSFER

A Cost Share Agreement was negotiated with Foster-Miller, Inc. in FY95, to provide design enhancements and facilitate transfer of the SPCS technology to Foster-Miller for potential commercial development. Under the Cost Share Agreement, Foster-Miller has been granted nonexclusive rights to the SPCS technology.

Accomplishments

- Significant modifications were made to the prototype system to improve maneuverability, increase travel range, and minimize tether diameter.
- A Cost-Share Agreement was placed with a commercial partner for much of the modification work.
- The modified SPCS was demonstrated at a major programmatic technology demonstration. Demonstrated features included video inspection, horizontal and vertical travel, selective steering, cornering, and the ability to transition between two- and three-inch pipe "on the fly."

TTP Information

The Small Pipe Characterization System activities are funded under the following TTPs:

TTP No. ID75C121, "Robotics INEL Rollup"
TTP No. OR15C141, "Robotics ORNL Rollup"

Contact

Dennis C. Haley
D&D Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, TN 37831-6304
(423) 574-5691
e-mail: haleydc@ornl.gov

Walter D. Willis
Principal Investigator
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-2220
(208) 526-8613
e-mail: davew@pmafire.inel.gov

Bibliography of Key Publications

None at this time.

3.5 Internal Duct Characterization System

Technology Needs

Across the DOE complex there are numerous facilities identified for D&D that have been placed on the contaminated list because of the risk of internal contamination in duct work. Most of this duct work is inaccessible because it is buried underground, encased in concrete, or runs through hot cells. Duct work characterization is extremely difficult because of airflow control devices, varying sizes and geometry of the work, and numerous changes in duct direction. Characterization of this work is essential before, during, and after D&D activities. The identification and mapping of contaminants is a major concern during facility deactivation. An understanding of the types and extent of contamination will be primary drivers for decisions regarding decontamination and/or dismantlement. These decisions will affect initial deactivation cost, ongoing surveillance and maintenance risk and cost, and eventual D&D strategy and costs. Identifying sections of the ducts that are not contaminated can greatly reduce the amount of material sent to waste handling facilities for decontamination/disposal. Conventional methods have been applied to the characterization of duct work with some success, but this has been at the risk of human exposure to high levels of contamination. Commercially available remote duct work characterization systems are limited in their capabilities. A robotic/remote duct characterization system with extended travel capability that can perform chemical and radiological contaminant characterization and selected hot spot decontamination or partial duct work dismantlement is needed.

Technology Description

The Internal Duct Characterization System (IDCS) activity provides for the design, fabrication, procurement, and demonstration of a remotely operated system for visually inspecting ventilation duct work and characterizing selected chemical and radiological contaminants that are internally located in ventilation duct work. The IDCS, shown in Figure 3.5-1, consists of a control station, a reel-mounted tether for data communication, and a pipe crawling vehicle. The IDCS vehicle can travel over 200 feet in round ducts six inches in diameter and larger, and in rectangular ducts six inches square and larger. The vehicle visually inspects the interior condition of ducts using a high-resolution color video camera, and has an integrated radiation sensor to detect significant levels of radioactivity. The entire vehicle is made from stainless steel and is designed to be decontaminated. The IDCS system also provides limited contaminant sampling and decontamination capabilities.

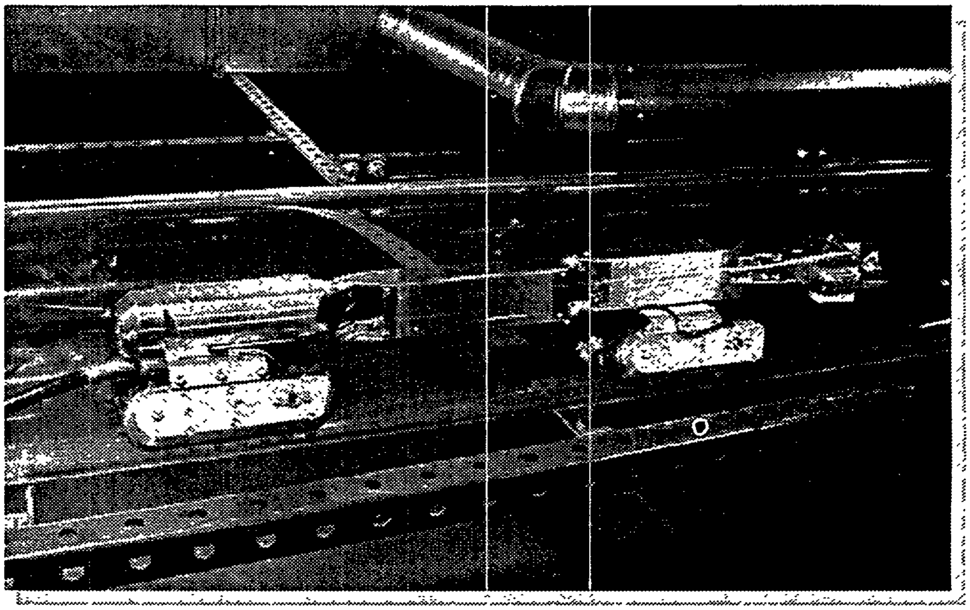


Figure 3.5-1. Internal Duct Characterization System in 8-inch Round Duct.

Benefits

This technology allows characterization of duct work that otherwise could not have been characterized. Determining the absence or presence of contamination and the extent of contamination in duct work will reduce the costs of D&D activities by allowing the duct work to be handled appropriately as opposed to treating all work as contaminated. It will also reduce the amount of secondary waste generated since uncontaminated duct work will not need to be decontaminated. It will reduce human health risk because sections of duct work that pose health risks will have been identified prior to exposure. Using this technology to perform in situ decontamination would provide additional benefits in the areas listed above.

Collaboration/Technology Transfer

This technology has been developed by INEL in collaboration with private industry. Performance requirements for this task were developed at INEL, but much of the design and fabrication was performed by a team of two Canadian companies: Inuktun Services, Ltd., and Automation Systems Associates, Ltd., both located in British Columbia. All the technology developed under this activity is now commercially available, with the patent rights for everything except the drive reconfiguration mechanism held by the industrial partners.

Accomplishments

- The IDCS was used to inspect over 200 feet of contaminated offgas ducting at an operating DOE facility.
- The IDCS control system was upgraded to provide for the addition of sensors and motors.
- A drive reconfiguration mechanism was designed, built, and installed to allow "on the fly" adaptation to varying duct sizes and geometries.
- A vertical travel carriage was designed and built through an industrial procurement.
- The improved IDCS was demonstrated at a major programmatic technology demonstration.

TTP Information

The Internal Duct Characterization System is funded under the following TTPs:

TTP No. ID75C121, "Robotics INEL Rollup"
TTP No. OR15C141, "Robotics ORNL Rollup"

Contacts

Dennis C. Haley
D&D Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, TN 37831-6304
(423) 574-5691
e-mail: haleydc@ornl.gov

Walter D. Willis
Principal Investigator
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-2220
(208) 526-8613
e-mail: davew@pmafire.inel.gov

Bibliography of Key Publications

McKay, Mark D., and Walter D. Willis. *Internal Duct Characterization System, Specification Number* R0007098, Rev. 3. (1994).

3.6 Reduced Access Characterization Subsystem

Technology Needs

Many facilities exist in the DOE complex that have become radiologically contaminated through years of research and service. These facilities include hot cells, glove boxes, fuel storage buildings, and process buildings. As many of these facilities are prepared for D&D, the need arises for surveillance and characterization before, during, and after cleanup activities. Characterization is currently being performed in these areas by having a radiation control technician manually monitor radiation levels with hand-held instruments. Although this method is effective for small or hard to reach areas, automated floor characterization systems can be much more effective in larger buildings such as the 300+ acre K-25 facility located at ORNL. During the past two years, a large Mobile Automated Characterization System (MACS) has been developed jointly by the SRTC and ORNL. The MACS platform is designed to carry multiple radiation sensors and perform automatic floor characterization of large areas. During the development of MACS, it was found that a significant floor area exists in most facilities that is not readily accessible by a large-floor characterization system. The Reduced Access Characterization Subsystem (RACS) is being developed to operate as a subsystem of MACS and provide characterization of areas inaccessible to MACS.

Technology Description

The RACS activity provides for the development and demonstration of a stand-alone robotic floor characterization system that can work cooperatively with MACS to perform tedious floor characterization and provide superior radiological data collection and storage. The RACS system, shown in Figure 3.6-1, consists of the RACS robot, which is based on a commercially available robot, and a homing/repeater beacon called TRACS. In a typical inspection, RACS and TRACS will be carried on a platform onboard MACS. When MACS arrives at a limited access region, the MACS operator will send

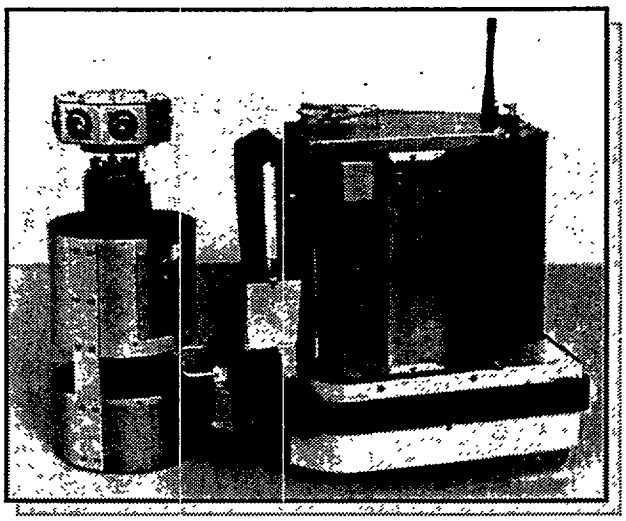


Figure 3.6-1. RACS Robot and TRACS Homing/Repeater Beacon

a deploy command to RACS, which incorporates current global position of the MACS robot and coordinates of the area RACS is to survey. RACS then leaves MACS, drops the TRACS beacon, and surveys the area specified while MACS continues its survey. RACS will transmit radiation and position data back to MACS via TRACS where it is incorporated into the facility map. When RACS has completed its survey, it will retrieve the TRACS beacon and wait until MACS returns. When MACS is in position, RACS will receive a stow command and board its carrying platform on MACS. RACS can also be used as an independent system, if necessary.

BENEFITS

This technology will allow automated characterization of floor areas that could not have been characterized by larger automatic floor characterization systems. Automated floor characterization, particularly of large areas, can be done much more quickly than manual methods. In addition, the data obtained from automated floor characterization will be more detailed and accurate than manual methods, and can easily be integrated into an overall facility map. The use of automated systems will remove radiation control technicians from potentially hazardous areas and reduce overall personnel exposure by identifying areas that pose health risks prior to possible personnel exposure.

COLLABORATION/TECHNOLOGY TRANSFER

This technology has been developed at INEL in collaboration with private industry. All the robotic equipment used in the development of RACS has been procured to INEL specifications from IS Robotics, Inc.

ACCOMPLISHMENTS

- The RACS robot and TRACS beacon were procured from industry.
- RACS behaviors for deployment and surveying a rectangular area have been written and incorporated into the system.
- The interface to the radiation sensor was completed and radio transmission of RACS data back to MACS was accomplished.
- RACS was demonstrated at a major programmatic technology demonstration.

TTP Information

Reduced Access Characterization Subsystem activities are funded under the following TTPs:

TTP No. ID75C121, "Robotics INEL Rollup"
TTP No. OR15C141, "Robotics ORNL Rollup"

Contacts

Dennis C. Haley
D&D Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, TN 37831-6304
(423) 574-5691
e-mail: haleydc@ornl.gov

Walter D. Willis
Principal Investigator
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-2220
(208) 526-8613
e-mail: davew@pmafire.inel.gov

Bibliography of Key Publications

Anderson, M.O., M. D. McKay, and B. S. Richardson. "Multirobot Automated Indoor Floor Characterization Team," presented at the IEEE International Conference on Robotics and Automation, Minneapolis, Minnesota (April 1995).

3.7 FULL-SCALE TESTING

TECHNOLOGY NEEDS

Full-scale testing of the Selective Equipment Removal System/Dual-Arm Work Module (SERS/DAWM), developed under the RTDP D&D application area, and the large payload mobile platform Rosie, developed under a Morgantown Energy Technology Center (METC) contract, is required to demonstrate the viability of using robotic systems to address real DOE site D&D problems. The Robotics Technology Assessment Facility (RTAF), Figure 3.7-1, was established in FY95 at ORNL to provide an experimental facility capable of supporting such full-scale testing.

TECHNOLOGY DESCRIPTION

In FY96, the RTAF facility will be used to support full-scale testing of dismantlement scenarios for the CP-5 reactor at the Argonne National Laboratory (ANL). CP-5 task level mock-ups will be installed in the RTAF. Dismantlement scenarios will be performed and evaluated under realistic operational conditions.

BENEFITS

This full-scale testing will provide cold testing and training opportunities that are critical to successful field deployment of remote systems.

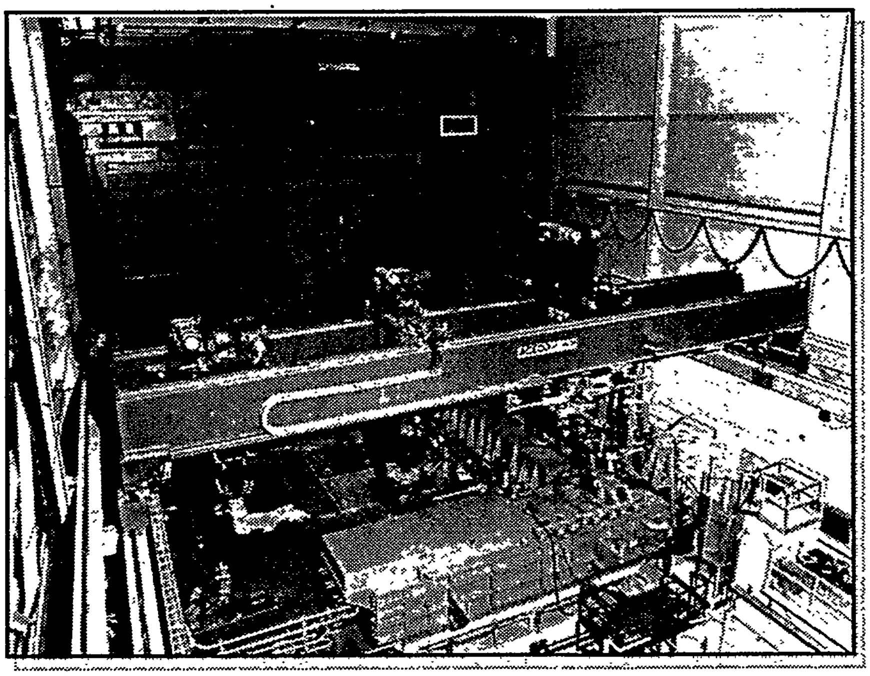


Figure 3.7-1. ORNL Robotics Technology Assessment Facility.

Collaboration/Technology Transfer

This technology is being jointly developed by ORNL, SRTC, SNL, INEL, ANL, RedZone Robotics, Inc., Carnegie Mellon University, and Machine Kinetics, Inc.

Accomplishments

- During FY95, the RTDP presented a demonstration of robotic and remote handling systems being developed for the D&D Robotics Program. These demonstrations were held in the RTAF. Three characterization systems and two dismantlement systems were featured in this demonstration.
  - Floor characterization was represented by the Mobile Automated Characterization System (MACS) and the much smaller Reduced Access Characterization System (RACS).
  - Pipe characterization was demonstrated by the Small Pipe Characterization System (SPCS). This system was operated in a run of clear plastic piping for demonstration of pipe traverse including travel through elbows and tees as well as transition between pipe sizes (diameters).
  - The Internal Duct Characterization System (IDCS) demonstrated duct characterization in a test setup of clear, round duct work as well as round and rectangular metal duct work. Another version of the IDCS capable of traversing vertical duct work was demonstrated as well.
  - Dismantlement tasks were performed by the Rosie work vehicle and the DAWM.
  - The DAWM was deployed on an overhead transporter and was used in teleoperation mode to demonstrate the destructive dismantlement of representative process equipment.
- The control room used for operation of the DAWM was also demonstrated. The demonstration consisted of a presentation of the teleoperation interface and several enhancements under development, which are designed to increase the efficiency and effectiveness of robotic dismantlement systems.

TTP Information

Full-Scale Testing is funded under the following TTPs:

TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. SR16C151, "Robotics SRTC Rollup"
TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. ID75C121, "Robotics INEL Rollup"

CONTACT

Dennis C. Haley
D&D Coordinator
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, TN 37831-6304
(423) 574-5691
e-mail: haleydc@ornl.gov

BIBLIOGRAPHY OF KEY PUBLICATIONS

None at this time.

3.8 HOUDINI RECONFIGURABLE IN-TANK ROBOT

TECHNOLOGY NEEDS

At many DOE sites, there is a need for retrieval of residues and discrete objects from Underground Storage Tanks and Aboveground Storage Tanks, also referred to as waste silos. What is needed is a remotely operated manipulator system that can fit through small apertures to enter tanks and do work within them through a range of tooling options. They should be capable of working alone or in conjunction with other bulk retrieval methods. They are also required to locomote on or under waste surfaces while tolerating hostile radiological, chemical, and physical conditions. Because of the duration of some anticipated applications, operability of controls, efficacy, and operating efficiency are also important attributes.

Two sites have already identified a specific need, and this class of remediation challenge is common across DOE. At the Fernald Environmental Management Project, remote vehicles have been identified as the only way of completing the final remediation of their Operable Unit 4 (OU 4), whose Record of Decision was signed with the U.S. Environmental Protection Agency (EPA) in late 1994. The contents of its two silos of clay-like K-65 material will be principally removed by sluicing, and the powdery oxides of a third silo will be pneumatically retrieved. However, many discrete objects such as tools and glove bags are also in the silos and pose a threat to primary sluicing and vacuum equipment. Furthermore, a "heel" of residue and other objects will be left in all three silos after primary retrieval is concluded. This type of system is thus needed for heel removal, discrete object sizing and retrieval, and possibly decontamination tasks. Over 13,000 cubic yards of material will be extracted in three years. ORNL has also identified an application for such a robot in their Gunite and Associated Tanks OU. This is seen as a key technology in their shorter duration campaign, intended to retrieve waste from several underground storage tanks as part of CERCLA treatability studies due by the end of FY97.

TECHNOLOGY DESCRIPTION

Houdini is a tethered, hydraulically powered, track-driven, teleoperated work machine with an expandable frame chassis that allows it to fit through a typical 24-in. opening. Dimensions of the unfolded base are 44 in. wide, 48 in. long, and 10 in. high. The vehicle is capable of locomoting over and through a variety of waste forms. It can operate fully submerged as long as sufficient support and traction are available, such as the tank floor. It can be retracted by its tether, which contains a strength member, and can fold under gravity if equipment failure warrants it. A heavy duty dextrous manipulator capable of lifting 240 lb. at full extension is fitted on the mobile base.

When not deployed, the folded machine is retracted into the Tether Management and Deployment System (TMADS), which seals the robot, tether, and its drum in a shielded storage and transport container. Hydraulic power and machine controls are housed in a separate Power Distribution and Control Unit (PDCU), located in an environment unexposed to tank contents.

Intended applications include residue retrieval, washdown and slurry, remote sizing, and discrete object manipulation. Other possible tasks include remote inspection of other in-tank equipment, support to primary retrieval equipment under failure scenarios, and decontamination of the emptied tank. To support these tasks, the robot is fitted with a plow blade, removable squeegee, and gripper that are used in conjunction with tooling that include scoops, a shear, a vacuum hose interface grip, and a sump pump and hose reel assembly used for localized sluicing. Operations are controlled from a remote console that can be integrated with other retrieval equipment or housed in a small trailer. Task feedback includes two on-board video channels, audio, machine health status, and two overhead cameras. A provision has also been made to integrate the ORNL and RTDP-developed Position and Orientation Tracking System (POTS), to report the machine's position, orientation, and configuration within the tank.

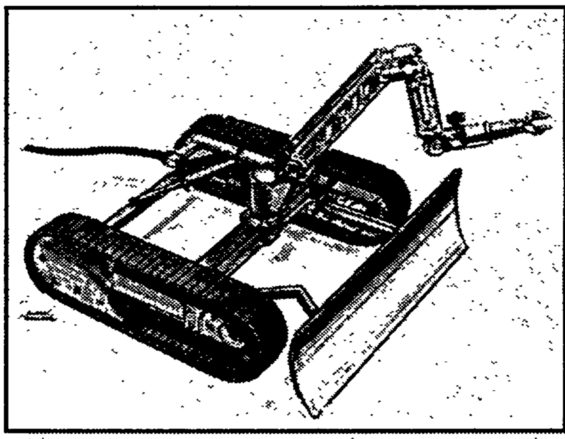


Figure 3.8-1. Houdini In-Tank Robot, artist conception.

The Tanks Focus Area is expected to benefit from this advancement in waste retrieval. At present, the first full prototype is being fabricated to performance specifications that have been developed at Fernald with ORNL input. A cold test in the summer of 1996 at the vendor's facility will demonstrate the system, integrated with POTS, in a silo mockup filled with surrogate material. System testing will then continue at ORNL and culminate with the hot deployment of Houdini at the Gunite and Associated Tanks OU in early FY97. Lessons learned during early deployment will then be incorporated into the design for a second unit to be used in the much longer waste retrieval campaign at Fernald. Further control improvements enhancing operability will also be considered at that time. POTS feedback, in conjunction with other improvements, may allow for telerobotic control for some repetitive or safety-critical tasks.

BENEFITS

Houdini provides functionality that enables the completion of tasks for which there are currently no practical alternatives, particularly in-tank heel removal and object retrieval. By providing remote locomotion, inspection, and retrieval within the tank, personnel entry into these confined and highly hazardous spaces can be avoided altogether, thereby reducing the radiation dose and overall program costs. It can decontaminate the tank interior to levels at which entry for dismantlement is much more feasible. It also provides a back-up system for possible, though unlikely, scenarios involving the failure of other in-tank equipment or the accidental introduction of foreign material into the tank.

COLLABORATION/TECHNOLOGY TRANSFER

The technology is being developed by RedZone Robotics, Inc., Pittsburgh, Pennsylvania, funded by EM-50 through Morgantown Energy Technology Center's (METC) Industry Programs. The intent of the vendor is to make this system commercially available upon completion of the program. Project coordination and technical specifications are being provided by Fernald under this TTP. ORNL has developed the POTS prototype primarily with RTDP support and has also participated in Houdini design reviews. EM-40 contractors at Fernald have given key design guidance, integrated Houdini into project plans for the remediation of their OU 4, and contributed equipment that will be integrated with the system to be used at Fernald. EM-40 and Tanks Focus Area staff at ORNL conducted a review that concluded that Houdini was the best approach to this application, and have now requested that the first prototype be tested at the Gunite and Associated Tanks OU so that they can successfully complete near-term CERCLA milestones.

ACCOMPLISHMENTS

- Developed operation scenarios for use of Houdini at Fernald.
- Completed design basis document and pre-fabrication design reviews.
- Coordinated technical and equipment contributions from vendor, ORNL, and Fernald's OU 4.
- Integrated Houdini constraints and requirements into Fernald's final waste retrieval system design.
- Identified near-term application of Houdini at ORNL.
- ORNL "bake-off" process selected Houdini as best approach for Gunite and Associated Tanks deployment.
- Outlined acceptance tests to be run on the first prototype this summer.

TTP Information

The Houdini Reconfigurable In-Tank Robot is funded by the following TTPs:

TTP No. OR15C141, "Robotics ORNL Rollup"
TTP No. OH15C181, "Application of Robotics Systems at Fernald"

Contacts

F. Brack Hazen
Principle Investigator
FERMCO
MS 81-2, P. O. Box 538704
Cincinnati, OH 45253-8704
(513) 648-6554
e-mail: Brack.Hazen@fernald.gov

Barry Burks
Tanks Waste Retrieval Coordinator
Oak Ridge National Laboratory
P. O. Box 2008, Building 7601
Bethel Valley Rd.
Oak Ridge, TN 37831-6304
(423) 576-7350
e-mail: burksbl@ornl.gov

Vijendra P. Kothari
DOE Project manager
Morgantown Energy Technology Center
P. O. Box 880
Morgantown, WV 26507-0880
(304) 285-4579
e-mail: vkotha@metc.doe.gov

Bibliography of Key Publications

Slifko, A. D., B.R. Thompson and H. Schempf. "Houdini: Reconfigurable In-Tank Robot," *Proceedings of Waste Management* '96, Tucson, Arizona (1996).

4.0 ROBOTICS CROSSCUTTING AND ADVANCED TECHNOLOGY

Crosscutting & Advanced Technology (CC&AT) addresses environmental problems severe enough to cause human beings significant risk to their health and safety. These problems are typified by the following:

- Underground waste storage tanks at Hanford, Washington and Oak Ridge, Tennessee, shown in Figure 4.0-1
- Highly contaminated radioactive material processing facilities such as those located at Rocky Flats, Colorado and Savannah River, South Carolina
- Buried waste sites such at the Idaho National Engineering Laboratory

Tanks at the first two facilities are in danger of leaking nuclear and/or hazardous waste material into the environment. They call for immediate solutions such as that shown in Figure 4.0-2. The retired material processing facilities must be cleaned and dismantled to eliminate the high maintenance and monitoring costs that continue, even though the facilities are no longer operating. Buried waste sites must be cleaned up to prevent migration of the contaminants into the soil and water table.

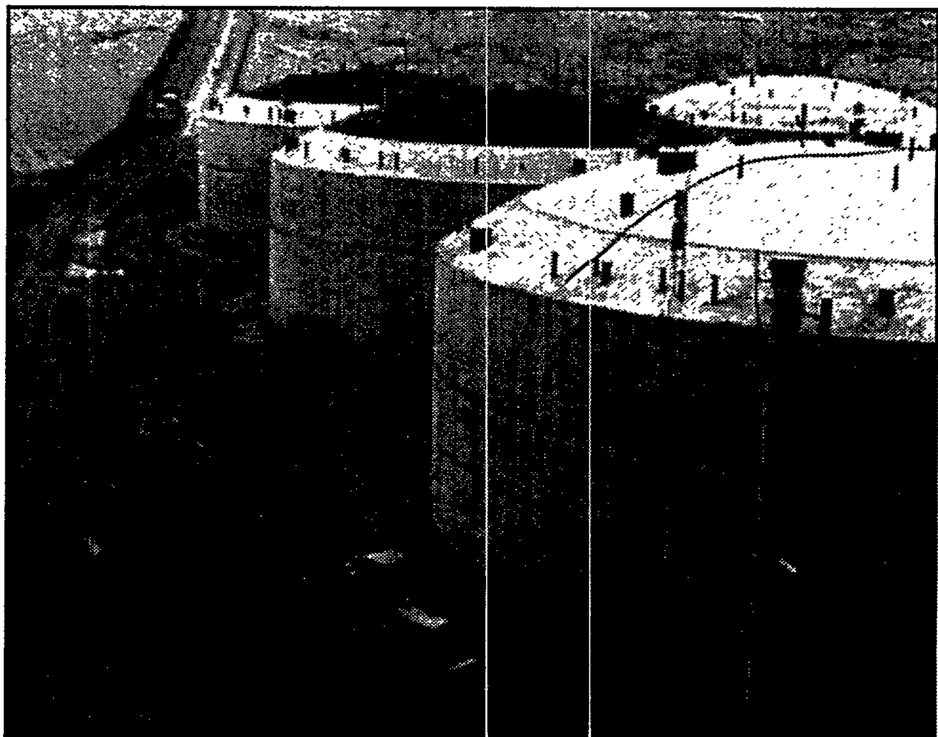


Figure 4.0-1. Operations inside underground storage tanks like these in this 1970's Hanford construction photo can only be done remotely because of high radiation levels.

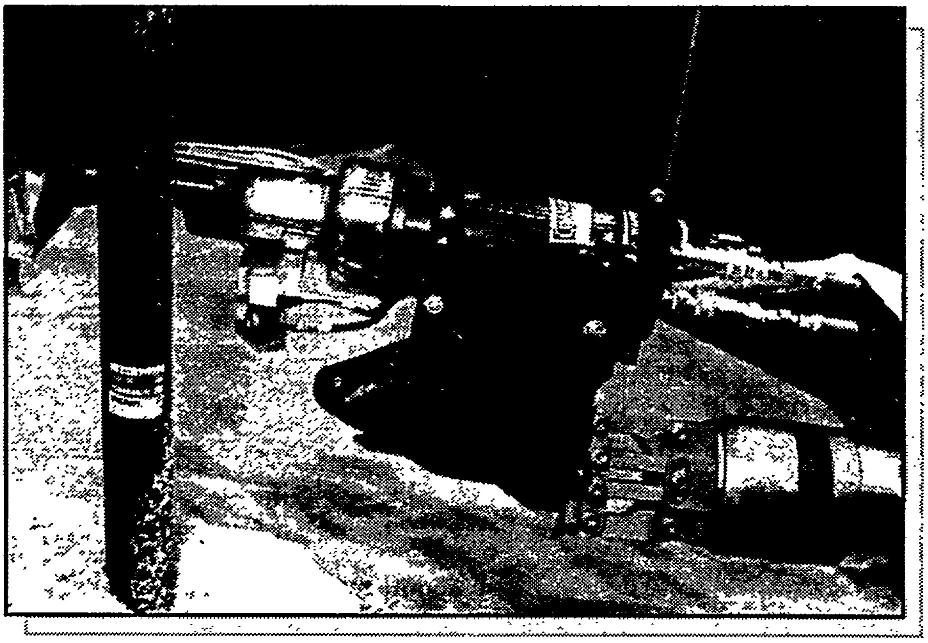


Figure 4.0-2. Robots can operate inside waste tanks to remove obstructions and maneuver equipment that removes the waste for treatment and final disposal.

The work performed by the Robotics Technology Development Program (RTDP) addresses these problems with specific task areas:

- Tank Waste Retrieval
- Chemical Analysis Automation
- Decontamination and Dismantlement

The CC&AT team within the RTDP develops technologies that are used to support all those task areas. The CC&AT program element is designed to address the generic, long-term technology development needs identified within DOE's environmental management efforts and RTDP. Projects have been directed toward the following solutions:

- The development of a generic, graphical robot controller based on an integrated multi-sensory system
- Systems analysis and modeling capabilities to evaluate target approaches
- Coupling sensor-based modeling with automated programming of robot operations as a key approach to developing faster, safer, and cheaper waste cleanup systems

Common technology needs within RTDP influence the effectiveness of all of the program's technical areas. Responses to long-term technology, research, and development efforts (while interfacing with representatives from industry, universities, and other federal agencies) are essential to CC&AT's continued growth and to the effective dissemination of technology developed under RTDP to the commercial sector.

For a more complete review of CC&AT technologies, consult the World Wide Web at http://www.sandia./gov/cc_at/1cc_at.html .

The RTDP Five-Year Plan states that robotic technologies used during waste cleanup should display the following characteristics:

- Allow easy manual operation because the ill-defined environments characteristic of many waste sites require close operator monitoring and control
- Require a minimum of specialized operator training while maintaining high safety and reliability
- Have operator interfaces designed to minimize operator error and maximize overall system productivity
- Have enough intelligence to detect and prevent operator errors while maintaining active operator involvement
- Be as generic and widely applicable as possible to EM activities within the DOE complex
- Be flexible in operation in order to deal with situations not anticipated prior to the start of waste management and remediation projects

To support technology developments that meet the characteristics identified in the Five Year Plan, CC&AT partitions robotic technology development into the following Major Thrust areas. Additional information on each thrust area can be found at the indicated URL addresses:

- Robotic Controls and Enabling System Software

  - http://www.sandia./gov/cc_at/Controls.html
- User Interface for Supervisory Control

  - http://www.sandia./gov/cc_at/Controls3.html
- Virtual Collaborative Environment

  - http://www.sandia./gov/cc_at/VCE1.html
- System Analysis for Cost Benefit Studies and Component Testing

  - http://www.sandia./gov/cc_at/Systems.html
- University R&D Programs

  -http://www.sandia./gov/cc_at/University.html
- Transfer of CC&AT

  - http://www.sandia./gov/cc_at/1cc_at.html

The primary goal of CC&AT is the development of robotics technologies broadly applicable to the EM needs of DOE. All of the technologies and techniques of waste remediation being developed by the CC&AT team are directed at faster, safer, and cheaper ways of performing these tasks.

Faster: The time for waste site remediation must be reduced to minimize the potential for environmental damage. Reduced time takes the form of:

- Faster operating systems which reduce site cleanup times
- Reduced maintenance time
- Reduced operator training time for simpler systems
- Reduced technology development time to meet aggressive waste cleanup schedules

Safer: Advanced technologies must reduce the hazards associated with waste cleanup by:

- Removing remediation technologists from hazardous environments
- Preventing equipment hazards such as collisions
- Enforcing safe operating procedures by preventing human overrides

Cheaper: Reduced life-cycle cost for site remediation must result from CC&AT efforts by:

- Reducing the capital costs of the waste cleanup system (robotic and other equipment comprising the waste clean up system)
- Reducing the operating costs of waste remediation systems
- Reducing the maintenance costs for waste remediation equipment
- Reducing the costs of operator training
- Reducing technology development costs with broadly applicable approaches to be spread across many potential applications

Work for the CC&AT element of RTDP is collaboratively done by a multi-laboratory team consisting of Sandia National Laboratories (SNL), Oak Ridge National Laboratory (ORNL), Los Alamos National Laboratory (LANL), and Pacific Northwest National Laboratory (PNNL). Sandia serves as the coordinator for the CC&AT program element to integrate the activities at the four sites.

The CC&AT element of RTDP stresses close teaming among the participating laboratories to accelerate technology development while reducing overall costs. Additionally, the CC&AT program element sponsors and integrates technology development within industry, universities, and other government agencies that can significantly impact RTDP and lead to faster, safer, and cheaper waste clean-up capabilities. A strong emphasis is placed on the University R&D sector to leverage program funds for fundamental, long-term technology development needs with the extensive scientific and technological base already established by these institutions.

CONTACT

Daniel S. Horschel
Manager, Intelligent Systems Department I
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185
(505) 845-9836
e-mail: dshorsc@isrc.sandia.gov

4.1 Robotic Controls and Enabling System Software

Technology Needs

Past experience has shown that performing tasks with remotely operated equipment using conventional controls is much slower than hands-on operations. Conventional controls also make tasks very tedious and tiresome for the operator, for whom fatigue is a significant cause of mistakes and accidents. Control systems that integrate repeatedly performed autonomous execution of tasks with simpler, more intuitive manual controls that are not easily automated are required for safer and faster operations in all remote robotic applications, as shown in Figure 4.1-1. Improved controls can also reduce operator training time and costs.

Robotic systems being developed for deployment in DOE cleanup activities tend to be built from a custom combination of commercially available software packages and hardware components - manipulators, sensors, computer controlled electrical and hydraulic systems, operator hand controllers, and others.

A generic technology need for robotic systems is integrating "high-level" software that supports advanced operator controls and is able to easily, quickly, and reliably adapt to custom combinations of hardware and software components. This "enabling system software" needs to be highly modular to support mixing and matching software library modules as readily as hardware components are changed. A modular architecture also allows adding modules for controlling and/or communicating with new hardware and software tech-

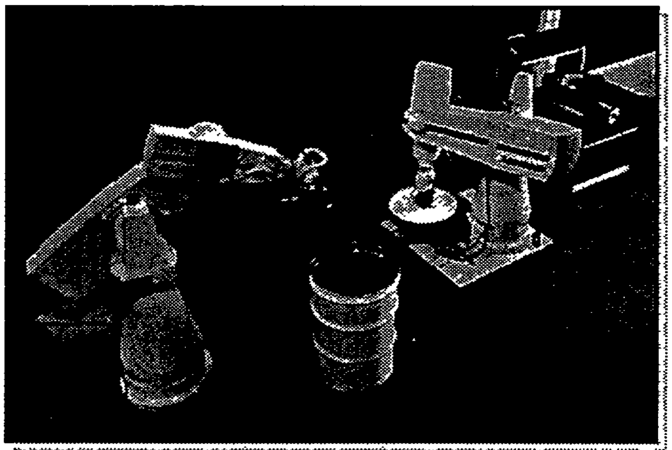


Figure 4.1-1. Advanced controls have been developed to provide true cooperative motion between multiple robotic arms so that complicated operations like disassembling contaminated equipment without dropping any pieces can be done quickly and easily.

nologies as they become available. A "plug-and-work" system is needed in which new control capabilities are synthesized by removing old modules, and plugging in new ones without extensive reworking of the rest of the system. Using well-characterized software modules in new applications also improves the overall reliability of the control software.

TECHNOLOGY DESCRIPTION

This task develops advanced control approaches to improve the speed with which robot systems can be assembled and integrated. The development of technologies that address advanced control issues that are applicable to all of the robot systems being developed for remediating DOE sites is emphasized in this task area.

Some of the major work areas for this task are:

- The development of Generic Intelligent System Control (GISC) modules that support the development and reuse of highly modular control software that is applicable to numerous diverse projects. Building software libraries that can be accessed electronically and used to implement advanced control systems rapidly is a key activity.
- The development of automated path planning techniques to efficiently control the motion of robots from one location or position to another. The robots must not collide with objects or attempt to bend into a configuration that they cannot reach because of the limited range of travel in the joints.
- The development of multi-robot controls to coordinate motions between robots. This work addresses the common situation where one robot (or robotic arm) is needed to hold a part while another performs an operation elsewhere on the part, such as cutting the part free. Coordinated control is also needed for multiple robots to carry large, bulky objects.
- The development of flexure models and control techniques to minimize bouncing or other undesirable motion in long manipulator arms and oscillations in crane payloads. Long-reach arms will flex and vibrate, and crane payloads will swing when they are moved using conventional controls; intelligent controls can minimize unwanted motions.
- The development of models and control techniques for transitioning from contact operations to noncontact operations. For both manual and autonomous operations, the motion control methods used to move a robot when it is unconstrained are inherently different than the methods used when a robot is in contact with large, heavy, or unyielding objects.

BENEFITS

The suite of capabilities developed by this task accomplish the following goals:

- Integrates computer models of the robot and its environment with real-time data from sensors to automate tasks and/or prevent collisions with objects.
- Allows seamless transfer between manual and autonomous control.
- Enhances safety by continually monitoring manual controls and automatically overriding inadvertent commands that would result in collisions, dropped tools, or other accidents.
- Enables technicians with little programming experience to program remote cleanup operations safely and easily through intuitive graphic interfaces.
- Allows operators to see and change planned robot movements before they occur by graphically previewing intended robot actions.
- Speeds operations by allowing operators to quickly automate tedious operations.
- Dampens undesired motions in long manipulators and crane payloads within a few seconds when motions would normally take several minutes to dampen naturally.
- Provides tools to make it possible to assess and optimize the performance of proposed hardware systems before they are fabricated.
- Enables task execution time studies with simulations to determine time and cost trade-offs between different methods.

COLLABORATION/TECHNOLOGY TRANSFER

All integrated system projects performed within RTDP are team-based and involve multiple laboratories and industry. The CC&AT activities are coordinated by Sandia National Laboratories. The generic systems control environment provided by the GISC approach and extensive reuse of control software stimulates collaborative technology development and expedites implementation of large integrated demonstration systems. Multiple laboratories and universities contribute to the development of GISC modules.

Commercial industrial interest in the GISC approach is high because it stimulates continued advancement towards a common industrial platform. A Cooperative Research and Development Agreement (CRADA) is in place with Deneb Robotics to further commercialize GISC software and provide a commercial source for this technology. A licensing agreement with Damas, a commercial bridge crane installation and service company, was signed to transfer technology that allows crane operations without payload oscillation. A collision avoidance system was transferred to Merritt Systems, Inc. through a CRADA, and in 1996 Merritt Systems, Inc. began commercial sales of the system.

The university partner for this task is Pennsylvania State University.

Many of the universities participating in the University R&D Program, as discussed in Section 4.5, are performing work that is directly tied to this task.

Accomplishments

Recent technologies developed in the CC&AT task area are demonstrated every July or August at the annual DOE Forum on Robotics for Environmental Management in Albuquerque. Further information on CC&AT work areas and on-line registration for the forum is available on the World Wide Web through the Forum web page at http://www.sandia.gov/cc_at/Forum96/1Forum96.html. Some of the technologies are also shown at irregularly-held demonstrations sponsored by other RTDP task areas. Recent accomplishments by CC&AT team members in the Robotic Controls and Enabling System Software development work area include:

- Libraries of Generic Intelligent System Control (termed GISC-Kit) software modules were made available over networks and used outside of the RTDP.
- GISC was used to operate robots in tank waste retrieval, decontamination and dismantlement, and contaminant analysis automation demonstrations.
- GISC-Kit documentation was made available and hands-on interactive classes taught.
- Advanced robot control algorithms for automated oscillation damping and flexure control were developed and codified into GISC-Kit modules.
- Precise 3-D computer models of objects and surfaces in a robot's workcell were rapidly constructed (within a few minutes) using data from laser scanners. Using the graphically displayed model, operators demonstrated the ability to program the robot to move around obstacles and perform autonomous contact operations with target objects almost immediately.
- A control system was demonstrated for automatic path planning of coordinated motions by a multi-armed mobile vehicle to be used in dismantling contaminated equipment.

TTP Information

Robotic Controls and Enabling System Software development work is funded under the following Technical Task Plans:

TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. OR15C141, "Robotics Technology Development Rollup" at ORNL
TTP No. LR35C111, "Robotics Technology Development Rollup" at PNNL

Contacts

Daniel S. Horschel
CC&AT Coordinator
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-9836
e-mail: dshorsc@isrc.sandia.gov

Michael J. McDonald
Senior Member Technical Staff
Intelligent Systems Department I
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-9852
e-mail: mack@isrc.sandia.gov

Bibliography of Key Publications

Gizelar, Angela, Reid Kress, Karen Bills, Dubey and Rajiv. "Modeling and Control of a Flexible-Link Waste Tank Clean-Up Manipulator Containing a Prismatic Joint and Hydraulic Actuator," 1996 WM *Symposium*, Tucson, AZ (Feb. 1996). Also *International Symposium on Intelligent Robotic Systems*, Bangalore, India (Nov. 1995).

Lew, J. Y. *Experimental Study on Macro/Micro Manipulator Vibration Control*, PNNL-SA-27368 (February 1996).

Lew, J. Y. "Vibration Control of Micro/Macro Manipulators", IEEE *Control System* (February 1996).

Jansen, John, and Reid Kress. "Controller Design for a Hydraulically Powered Dissimilar Teleoperated System," IEEE *Robotics and Automation Conference*, Minneapolis, Minnesota (April 1996).

Smalley, J. T. *Cross Cutting and Advanced Technology Large Hydraulic Actuator Test Bed*, PNNL 10885, Washington (October 1995).

Lew, J. Y. *Structural Vibration Control of Micro/Macro Manipulator Using Feed forward and Feedback Approach*, PNNL 10757, Richland, Washington (September 1995).

4.2 USER INTERFACE FOR SUPERVISORY CONTROL

TECHNOLOGY NEEDS

Remote operations in hazardous waste sites must be performed quickly and safely. Unfortunately, experience with remote manual operations indicates that such operations are slow, and that operator tedium can lead to reduced safety. A supervisory controller can monitor sensors and alert remote equipment operators about potentially unsafe operations or movements that might cause inadvertent collisions with objects. In addition, sensor information on remote environments can form maps that can be used by supervisory controllers to verify the safety of operator commands and automate certain tedious and repetitive operations. Faster methods are needed to process very large amounts of geometric mapping data and other information from sensors into a model of the world around a robot that a supervisory controller can use to plan robot motions, prevent collisions, and display to the operator. Improvements are needed in the computer interfaces an operator uses to make controls simpler and faster to use. Better ways for an operator to simultaneously control multiple robots are also needed to improve operator efficiency.

TECHNOLOGY DESCRIPTION

Human-machine interfacing employs human factor principles to assure efficient interactions, shown in Figure 4.2-1. Perhaps the most important sensory feedback to the operator is remote viewing, which includes both video images from cameras located on or near the robot and detailed 3-D graphical computer images. The User Interface for Supervisory Control task area includes work to

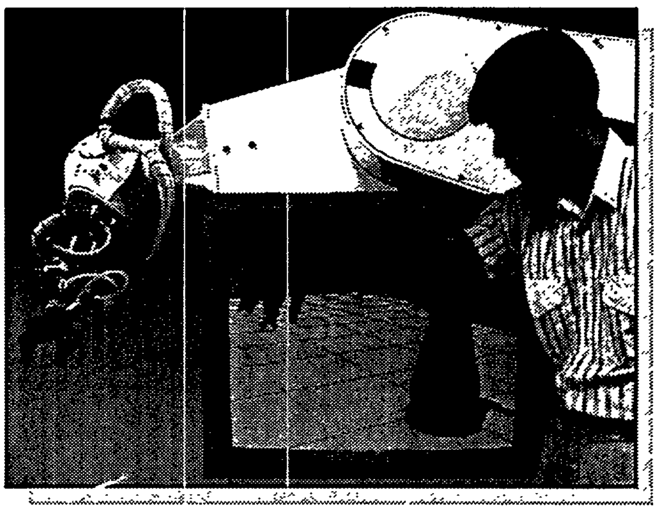


Figure 4.2-1. Advanced operator controls are easy to use because they are intuitive, safe to use because they "supervise" the operator to prevent collisions and other mistakes, and fast to use because the operator can concentrate on the task he/she wants to perform instead of how to move the robot.

develop detailed geometric mapping systems that can quickly use sensor data, process it, and display it to the operator in a world model environment. The operator can "fly through" the graphical world model to view the robot and its environment from any desired vantage point, not just those where cameras are located. Work is being done to build world models faster and make them more detailed and realistic looking.

Advanced technologies that provide nonvisual sensory feedback to an operator, such as force reflection, are also being developed in this task area. Such operator sensory feedback technologies must be carefully integrated into the overall robot system control so that the operator and sensor-based servo control systems do not work against each other. CC&AT development efforts stress the use of modular subsystems to allow ease of integration of human-machine technologies into robot systems.

Initial technology developments tend to use custom software, but commercial or generic software is much more cost effective to use in field applications. Part of the work in the User Interface for Supervisory Control task area is to improve robot system operator interfaces through the development of graphical displays that minimize the dependence on proprietary software and specific kinematic packages. This work area also emphasizes finding solutions to advanced controls issues that need to be resolved for effective site remediation, such as efficient multi-robot control and rapid automatic path planning and programming when a robot has complex surroundings.

BENEFITS

Detailed world models allow the automation of robot operations and the evaluation of operator-supplied commands to the robot to ensure that only commands resulting in safe operations are executed. When coupled with graphic interfaces, detailed world models also provide natural, intuitive operator interfaces for programming robots and previewing motions in the model. The geometric model underlying the graphic interface then automatically converts the graphic commands into the actual robot motion programs. With this technology, an operator can check that the robot actions have been properly programmed before the program actually moves any hardware. The geometric models used for high-level robot system control then form the basis for full-system simulations for design and analysis, thus inherently forming a tool for optimizing hardware designs and for performing time studies to evaluate cost effectiveness.

Improved visual and tactile feedback to an operator reduces errors, speeds operations, and reduces operator fatigue. Simpler and more intuitive graphical interfaces make it easier for an operator to program the supervisory controller to automate repeated actions, such as surveying large areas with radiation sensors, or highly complex motions, such as coordinated multi-robot movements. Increased automation can further improve the speed and safety of robotic operations.

Collaboration/Technology Transfer

Many of the universities participating in the University R&D Program as discussed in Section 4.5, are performing work that is directly tied to this task.

Accomplishments

Recent technologies developed in the CC&AT task area are demonstrated every July or August at the annual DOE Forum on Robotics for Environmental Management in Albuquerque. Further information on CC&AT work areas and on-line registration for the forum is available on the World Wide Web through the Forum web page at http://www.sandia.gov/cc_at/Forum96/1Forum96.html. Some of the technologies are also shown at demonstrations sponsored by other RTDP task areas. Some of the recent accomplishments by CC&AT team members in the User Interface for Supervisory Control development work area include:

- Using only a graphically displayed 3-D computer model of objects and surfaces in a robot's work cell, operators programmed the robot to move around obstacles and perform autonomous contact operations with only a mouse to "point-and-click" on objects in the model and pop-up menus containing a selection of operations. Using this graphical-based programming method, the operators were able to rapidly command the robot to perform operations on target objects.
- Using data from laser scanners, precise 3-D computer models of objects and surfaces in a robot's work cell were constructed and read into the graphical-based programming software system in an order of magnitude faster than previously possible (minutes instead of hours).
- After scanning surfaces with magnetic and thermal sensors, data interpretation algorithms could identify and locate objects below the surface. The results were displayed in the graphical model of a robot's environment to indicate the location and shape of hot spots and hidden objects to the operator.
- Automatic camera pointing systems that track the orientation of an operator's head while the operator uses an inexpensive headset designed for home video games were demonstrated to provide the operator with a strong sense of presence in a remote robot's work cell. The enhanced telepresence was shown to improve operator speed and accuracy in performing manual operations.
- Through-the-window control displays, which reflect images from projectors onto curved mirrors mounted inside an enclosure, were demonstrated to provide enhanced telepresence for the operator. Because the

reflected image moves as the operator moves his/her head around, the display provides the strong illusion that the operator is looking through a window to the remote location, thereby improving the operator's spatial orientation.

TTP Information

User Interface for Supervisory Control development work is funded under the following TTPs:

TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. AL15C131, "Robotics Technology Development Rollup" at LANL

Contact

Michael J. McDonald
Senior Member Technical Staff
Intelligent Systems Department I
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-9852
e-mail: mack@isrc.sandia.gov

Bibliography of Key Publications

Draper, J. V. and L.M. Blair. "Workload, Flow, and Telepresence During Teleoperation," *Proceedings of the* 1996 IEEE *International Conference on Robotics and Automation*, Minneapolis, MN (April 1996).

4.3 Virtual Collaborative Environment

Technology Needs

In robotic applications where the operator is not able to enter or directly see the work (e.g., inside a waste tank), robotic machines need to be brought virtually to the operator's control station with simulated images, or graphical representations and video images. With videoconferencing, the operator can communicate through only a digital network, such as Internet, without any direct video link. With a completely digital system, the operator can be located anywhere, not just close to the work site, and multiple operators at multiple sites can work together to control the robot. This capability also makes it possible for a researcher or operator at one location to explore the possible utility of software that has been developed at a different location (e.g., a laboratory or university) by a different worker as shown in Figure 4.3-1. They can then test its effectiveness on robotic hardware that is installed at a third site, such as the equipment fabrication facility where hardware is tested before being deployed. The virtual linking of multiple operators and sites can greatly speed up development work, make very expensive and unique equipment accessible to many different control developers, and reduce the amount of travel required by distributed collaborators. For safety and efficiency, methods need to be developed to coordinate and simplify operations in such a virtual collaborative environment (VCE).

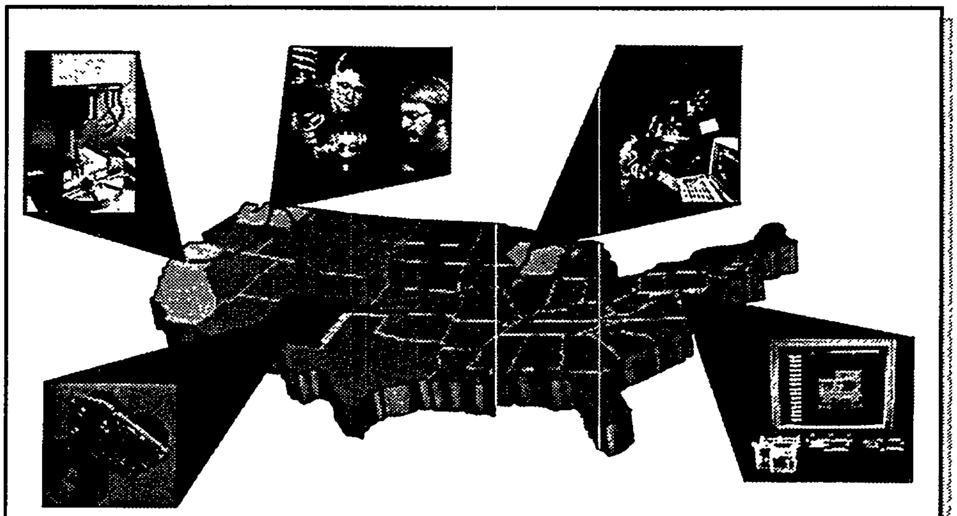


Figure 4.3-1. Virtual collaborative environments (VCEs) allow researchers across the country to use computer networks to test their new software and sensors on expensive DOE robots in real time without ever leaving their laboratories.

Technology Description

VCEs are information architectures that make it possible to share electromechanical resources including robots, machine tools, sensors, or other machine systems and software resources across great distances. VCE technology is a powerful tool for robotics and remote technology development.

VCE technology is derived from the integration of large computers with smaller machines. It foreshadows "The Factory of the Future" where it extends the mechatronic sharing of hardware and software to include distributed control stations, distributed data processing, and centralized hardware manipulation. Such sharing will reduce costs and increase quality. Sandia National Laboratory's (SNL) VCE effort is presented at: http://www.sandia./gov/cc_at/VCE1.html.

While the real hardware systems are working, multiple users can monitor that work in a parallel virtual environment to compare the actual work with the projected task. The real work then provides feedback to adjust the next operations. Network video links the user with remote TV cameras placed in the work environment. Other devices, such as force and position sensors, are used directly to monitor ongoing activities and system parameters. A wide range of important experiments can be performed using shared resources across the network before critical hardware operations are done in hazardous environments.

Benefits

VCE development in the RTDP builds upon robotics and remote technology R&D which has been developed at the numerous program areas. This work involves the utilization of computer control, simulation, and graphical modeling concepts in practical applications. In the short term, VCE technology enhances the ability to pursue this R&D as an integrated team that is geographically distributed across the United States. In the long term, the technology will allow operators to instantly work with off-site specialists as needed, without requiring them to travel to the site. Additionally, off-site regulators and stakeholders will be able to monitor and participate in critical operations.

VCE technology not only speeds the cycle of research to development to application, it can improve the user interfaces as the operator/developers inherently become familiar with the design tools needed to make it easy for them to program robots at a distance. Big pay-offs are expected in the increased ease of using robotic systems in this activity.

Collaboration/Technology Transfer

As indicated by its name, VCE technology inherently involves collaboration between distributed participants. VCEs have been established between SNL in New Mexico, ORNL in Tennessee, PNNL in Washington, and the National Institute of Standards and Technology (NIST) in Maryland. A primary thrust of this work area is to develop VCE technology that can be supported by common desktop computers and Internet connections instead of the high-end work stations and high-speed communication lines now required. This effort is directed at making this technology inexpensive and easy enough for university researchers and small businesses to collaborate with the national laboratories through VCEs.

Accomplishments

A high-speed communication network was established between SNL, ORNL, PNNL, and NIST. Equipment was operated at the DOE labs by NIST, and equipment at NIST was operated by SNL. Collaborative environments allowing workers at several sites to all interact simultaneously in the same design program was also demonstrated.

TTP Information

Virtual Collaborative Environment development work is funded under the following TTP:

TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL

TTP No. OR15C141, "Robotics Technology Development Rollup" at ORNL

Contact

Michael J. McDonald
Senior Member Technical Staff
Intelligent Systems Department I
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-9852
e-mail: mack@isrc.sandia.gov

Davies, B. R., R. W. Harrigan, and M. J. McDonald. "Remote Use of Distributed Robotics Resources to Enhance Technology Development and Insertion," *International Symposium on Robotics and Manufacturing* (ISRAM'94), Maui, Hawaii (August 14-18, 1994).

4.4 System Analysis for Cost-Benefit Studies and Component Testing

Technology Needs

There are a large number of technology options for the cleanup of waste sites. While robotics technologies offer significant potential for reducing the cost and time for waste cleanup while increasing safety, those advantages need to be analyzed to ensure that the most promising technologies receive highest priority. The economic costs and benefits of computer assisted robotic devices need to be evaluated to help direct and prioritize technology development efforts within the RTDP. Increased safety and reduced operating training costs resulting from the automation of tedious remote tasks need to be assessed. The high cost and long development times for integrated robotic systems have led to the need for advanced simulation technologies to support robot system design activities. Analytic tools are also needed to evaluate proposed robotic systems and to monitor procurement activities that involve design and fabrication of new robot systems, like those activities shown in Figure 4.4-1.

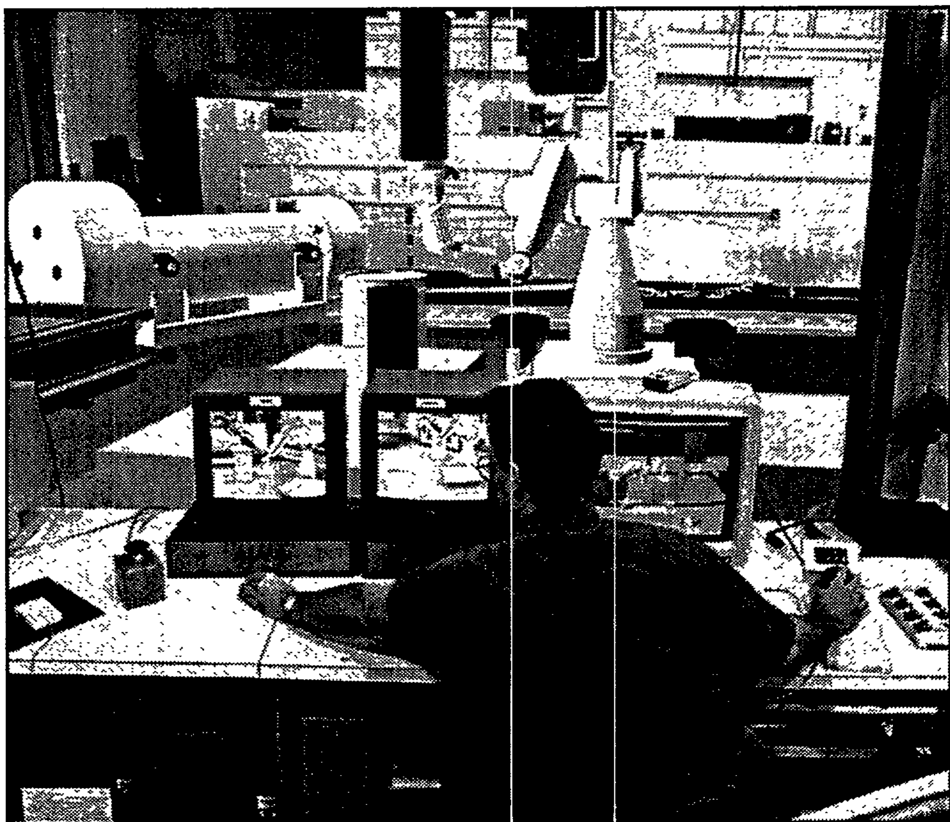


Figure 4.4-1. Detailed simulations of robots and their environments that are needed for robot control systems can also be used to conduct time-motion studies to evaluate the cost-benefit of different robots and control systems in performing specific tasks.

Technology Description

Faster, safer, and cheaper operation of complex robotic systems has led to the development of extensive computer simulations that capture information about the robot and its task environment (e.g., underground storage tanks, waste handling facilities, waste storage facilities, landfills, chemical analysis laboratories, old production facilities, etc.). As a result, the basic models are in place to support time studies for both manual and autonomous operation. This CC&AT subtask takes advantage of those models and links them with detailed cost analysis models to allow interactive simulation and analysis of advanced robot systems in waste cleanup applications. The models can determine which tasks are time intensive enough when done manually to justify programming efforts to automate the operations. The models can also be used to provide an accurate assessment of the total costs involved in building, deploying, operating, retrieving, and decontaminating a robotic system. This detailed cost assessment can provide a basis for comparing risks and benefits for the system against those incurred by alternate methods.

Benefits

This subtask identifies modeling needs to develop complete and detailed cost and risk analyses for specific robotic systems, and develops any new computer models for extension of the simulation capabilities to support cost-benefit trade studies. A critical activity within this work area is the validation of computer model results with actual operator experience running robotic systems whenever possible. The System Analysis for Cost-Benefit Studies and Component Testing work area thus couples the development of models with experimentation and component testing to validate models prior to their extensive use in design and evaluation. In addition, this work develops all models in a well formalized manner so that they can be used by all members of the RTDP with minimal reprogramming and customization. It is intended that eventually the models and simulation technologies developed within this subtask will be accessible nationwide over the evolving national information networks, thus allowing the models to be benchmarked against a much broader operational database resident with commercial robot manufacturers and operators.

Collaboration/Technology Transfer

Many of the universities participating in the University R&D Program, as discussed in Section 4.5, are performing work that is directly tied to this task. Developers of this work have interacted with the major DOE cleanup sites to gather information on operational experience to validate models.

Accomplishments

A joint Sandia National Laboratory/Oak Ridge National Laboratory report that illustrates application of the system analysis models to operations in underground storage tanks was recently issued.

TTP Information

System Analysis for Cost-Benefit Studies and Component Testing work is funded under the following TTPs:

TTP No. AL25C161, "Robotics Technology Development Rollup" at SNL
TTP No. OR15C141, "Robotics Technology Development Rollup" at ORNL
TTP No. LR35C111, "Robotics Technology Development Rollup" at PNNL

Contact

Kent deJong
Senior Member Technical Staff
Robotics Program Office
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-1750
e-mail: kedejo@isrc.sandia.gov

Bibliography of Key Publications

deJong, K, John Clever, J. V. Draper, and B. Davies. *System Analysis: Developing Tools for the Future*, SAND96-0521, SNL (1996).

4.5 UNIVERSITY R&D PROGRAMS

TECHNOLOGY NEEDS

True robotics is an emerging technology that integrates mechanical systems and various sensors with computers that control the mechanical systems based on "intelligent" interpretation of the sensor data and operator commands. Since the advent of small portable computers in 1980, it has been practical to control robots based on real-time information from sensors and operator controls. The rapidly-increasing power of portable workstations is continuously making more real-time decisionmaking by computers practical, thus simplifying demands on the human operators and enabling systems to operate faster, and do more complex tasks more reliably. Fundamental research and development work is needed to address many robotic issues that were never resolved or were never anticipated before now, because only recently has it become practical to apply sufficient computing power to advance the technology to a point where researchers can envision substantial improvements in robotic capabilities if these issues are solved.

TECHNOLOGY DESCRIPTION

The University R&D Program is using the extensive scientific and technological base already established by universities to address fundamental, long-term robotic technology development needs, such as:

- Advanced operator interfaces
- Better path planning
- Software safety and system reliability
- Improved robot manipulator control
- Advanced sensor interpretation
- Hardening of components against hazardous environments

All of the participants in the University R&D Program work on potential technology advances that would benefit one or more of the other components of the CC&AT task area, including:

- Robotic Controls and Enabling System Software
- User Interfaces for Supervisory Control

- Virtual Collaborative Control Environments
- System Analysis for Cost Benefit Studies and Component Testing
- Transfer of CC&AT Technology

The CC&AT element of RTDP stresses close teaming among the participants to accelerate technology development while reducing overall costs. As such, each university is assigned a DOE laboratory contact working in the CC&AT task area who helps ensure that the university work is done in close cooperation with those working elsewhere in the RTDP on related material. This monitoring ensures that the university work addresses the long-term needs of the RTDP without duplicating efforts elsewhere in the program.

The participants in the University R&D Program and their areas of work can be reviewed on the CC&AT web site at

http://www.sandia./gov/cc_at/University.html:

- Carnegie Mellon University: Programming environments for sensor-based robotic systems
- Carnegie Mellon University: Reconfigurable and modular robotic systems
- Case Western Reserve University: Reflex control for robot safety
- Colorado School of Mines: Machine health monitoring and prediction
- University of Florida at Gainesville: Hardened micro-sensors for robot control
- Georgia Institute of Technology: Algorithms for the stable control of large robot manipulators subject to structural vibrations
- University of Minnesota: Real-time servo control using computer vision
- New Mexico State University: Subsurface mapping of waste sites
- Pennsylvania State University: Applications of virtual reality concepts to robot system control
- Purdue University: Impact of redundancy on robot reliability
- Rice University: Robotic system failure mode analyses
- University of Tennessee: Control of force-reflecting telerobotic systems
- Washington University at St. Louis: Dual manipulator cooperative control
- University of Wisconsin at Madison: Whole arm sensing for collision prevention

Benefits

Focused, advanced technology development at universities sponsored by CC&AT emphasizes joint projects with the CC&AT Team, and leads to innovative waste cleanup solutions as well as stimulating movement of technology out of the university laboratory into prototypical operating systems that can be evaluated by site technologists. Innovative graduate student and faculty research is supported both by direct funding and by opening DOE laboratory facilities to university researchers.

Though research (university or other) is inherently difficult to quantify, projects performed under the university programs are addressing the issues of safety and speed, with resultant cost savings. In general, advances in robotics that allow substitution of mechanisms for human workers tend to improve safety. Due to the cost of human operation within hazardous environments, the use of robotics usually results in substantial cost savings. In addition, robotic systems may generate a significantly smaller secondary waste stream. Because such systems do not need continual protective clothing renewals and associated human-related equipment, they can often be easily decontaminated.

New Mexico State University's program, for example, is applying data interpretation algorithms to geophysical sensor data to develop detailed subsurface maps of objects and the migration of liquid waste. This program has had a direct impact on the cleanup of buried waste sites, and has made use of real geophysical data that was collected from INEL, Hanford, and Sandia. The benefits of this program will include faster access to objects in known locations, accurate characterization of the volume of contaminated soil, safer access from increased knowledge, and cost savings due to object-specific excavation.

Collaboration/Technology Transfer

The University R&D Program within RTDP's CC&AT task area is inherently a highly collaborative program that promotes technology transfer in both directions between the laboratories and the universities, and promotes transfer of university-developed technologies into the commercial sector. Areas in which university-based research will be pursued in a given year are determined by the CC&AT team based upon the RTDP Five Year Plan and identified site cleanup needs. The CC&AT team members include representatives from PNNL, LANL, ORNL, and SNL.

ACCOMPLISHMENTS

University researchers have been supporting needs that cut across the RTDP programs and specific task areas. Several general areas addressed by the University Program include safety and reliability issues related to placing robotic systems in hazardous environments. These issues include:

- Impact of kinematic and actuator redundancy on robot system reliability and safety
- Fault tree analysis of robot systems
- Software safety
- Hardened micro sensors
- Machine health monitoring

Universities have illustrated their efforts to address the unique safety issues of the DOE complex cleanup by conducting demonstrations with robot systems at the national labs. Results from research have been rapidly applied to the demonstration systems developed by the RTDP. Similar progress is being made in the following areas:

- Incorporation of servo control code for dual arm manipulation
- Modular robotics
- Control of force-reflecting telerobotic systems
- Algorithms for control of large robot manipulators

Several university programs support specific needs in RTDP. For example, New Mexico State University's program interpreting geo-physical sensor data to generate detailed subsurface maps of objects and the migration of liquid has had a direct impact on the cleanup of buried or leaking waste sites at INEL, Hanford, and Sandia.

TTP INFORMATION

CC&AT University Research and Development Programs work is funded under TTP No. AL25C161, "Robotics Technology Development Rollup" at Sandia National Laboratories.

CONTACTS

Daniel S. Horschel
CC&AT Coordinator
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-9836
e-mail: dshorsc@isrc.sandia.gov

Jerry D. Stauffer
Senior Member Technical Staff
IS&RC Program Office
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-8966
e-mail: jdstauf@isrc.sandia.gov

BIBLIOGRAPHY OF KEY PUBLICATIONS

Harrigan, R.W. "Research on Robotics by Principal Investigators of the Robotics Technology Development Program," *Sandia National Laboratories Report*, SAND94-0844 Albuquerque, New Mexico (March 1995).

4.6 TRANSFER OF CC&AT TECHNOLOGY

TECHNOLOGY NEEDS

The CC&AT program element develops widely applicable robotic technologies that will provide faster, safer, and cheaper remediation of waste sites than comparable approaches employing human entry into hazardous environments or manually controlled remote devices. It is not practical or cost effective for the laboratories to provide continuing support for the technologies once they are deployed to the field. It is in DOE's interest to transfer the developed technologies to commercial firms that can cost-effectively provide continuing support for both verified and validated software and production hardware.

TECHNOLOGY DESCRIPTION

This program area supports transfer of selected CC&AT-developed technologies into the commercial market place so that they are readily available to site remediators. Current emphasis is placed on establishing commercial availability of some GISC-Kit software at Deneb Robotics and a whole arm protection system at Merritt Systems Inc.

BENEFITS

System prototyping is employed to convince site remediation specialists that advanced robotic technologies are beneficial and ready for use. The CC&AT task area is the primary vehicle within the RTDP for ensuring that most of the technologies developed are successfully transferred to the commercial sector and available to DOE site remediation technologists, as well as to industries involved in the cleanup of non-DOE hazardous sites.

COLLABORATION/TECHNOLOGY TRANSFER

This work area is specifically provided to support technology transfer. This area has supported Cooperative Research and Development Agreements (CRADAs) with Deneb Robotics, Inc., Merritt Systems, Inc., and Schilling Development, Inc. Please see also the CC&AT web site at

http://www.sandia./gov/cc_at/IndustPartners.html.

Accomplishments

Merritt Systems, Inc. is now marketing a robotic whole-arm protection sensor system that was developed under the CRADA with Sandia National Laboratories. These sensors are being purchased for deployment in RTDP robotic development.

TTP Information

Transfer of CC&AT Technology work is funded under TTP No. AL25C161, "Robotics Technology Development Rollup" at Sandia National Laboratories.

Contact

Daniel S. Horschel
CC&AT Coordinator
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 845-9836
e-mail: dshorsc@isrc.sandia.gov

Bibliography of Key Publications

None at this time.

DOE Business Opportunities for Technology Development

Working with the DOE Office of Environmental Management

The Office of Environmental Management (EM) provides a range of programs and services to assist private sector organizations and individuals interested in working with DOE in developing and applying environmental technologies. Vehicles such as research and development contracts, subcontracts, grants, and cooperative agreements enable EM and the private sector to work collaboratively. In FY95, 39 percent of Office of Science and Technology (OST) funding went to the private sector, universities and other federal agencies. EM's partnership with the private sector is working to expedite transfer of newly developed technology to EM restoration and waste management organizations, industry, and other federal agencies.

Several specific vehicles address institutional barriers to effective cooperation and collaboration between the private sector and DOE. These mechanisms include contracting and collaborative agreements, procurement provisions, licensing of technologies, consulting arrangements, reimbursable work for industry, and special consideration for small businesses.

Information on EM

The EM Center for Environmental Management Information provides the most current facts and documents related to the EM program. Through extensive referrals, the Center connects stakeholders to a complex-wide network of DOE Headquarters and Operations Office contacts.

To obtain information from the EM Center for Environmental Management Information, write or phone:

EM Center for Environmental Management Information
U.S. Department of Energy
P.O. Box 23769
Washington, DC 20026-3769
1-800-736-3282
cemi@dgs.dgsys.com

The Cooperative Research and Development Agreement

The Cooperative Research and Development Agreement (CRADA) is a written agreement between one or more federal laboratories and one or more nonfederal parties through which the government provides personnel, facilities, equipment, and other resources, with or without reimbursement, to support a shared research agenda. The nonfederal parties may also provide funds, personnel, services, facilities, equipment, intellectual property, or other resources to support the research. DOE developed a modular CRADA to be responsive to the needs of participants while protecting the interests of the government and its taxpayers. DOE also has issued the small business CRADA to expedite agreements with small businesses and other partners that meet DOE's requirements. During FY95, EM entered into more than 60 CRADAs.

THE RESEARCH OPPORTUNITY ANNOUNCEMENT

The Research Opportunity Announcement (ROA) is a solicitation for industry and academia to submit proposals for potential contracts in basic and applied research, ranging from concept feasibility through proof-of-concept testing in the field. This mechanism is used when EM is looking for multiple solutions for a given problem. ROAs are issued annually by EM. The EM ROA provides multiple awards and is open all year. ROAs are announced in the *Commerce Business Daily*, and typically published in the *Federal Register*.

For questions on ROAs, contact:

Robert Bedick
U.S. Department of Energy
Morgantown Energy Technology Center
P.O. Box 880, D01
Morgantown, WV 26507
(304) 285-4505

To learn about EM Technology business opportunities, connect to the METC Homepage:
http://www.metc.doe.gov/business/solicita.html

THE PROGRAM RESEARCH AND DEVELOPMENT ANNOUNCEMENT

EM uses the Program Research and Development Announcement (PRDA) to solicit proposals from nonfederal parties for research and development in areas of interest to EM. The PRDA is used for projects that are in broadly defined areas of interest where a detailed work description might be premature. It is a tool to solicit a broad mix of applied research, development, demonstration, testing, and evaluation proposals.

For questions on PRDAs, contact:

Robert Bedick
U.S. Department of Energy
Morgantown Energy Technology Center
P.O. Box 880, D01
Morgantown, WV 26507
(304) 285-4505

To learn about EM Technology business opportunities, connect to the METC Homepage:
http://www.metc.doe.gov/business/solicita.html

The Small Business Innovation Research Program

The Small Business Innovation Research (SBIR) Program promotes small business participation in government research and development programs. This legislatively mandated program is designed for implementation in three phases from feasibility studies through support for commercial application. DOE publishes solicitation announcements through the Small Business Innovation Research Office each year to define research and development areas of interest.

For further information about SBIR programs, contact:

SBIR Program Manager
U.S. Department of Energy
Small Business Innovation Research Program
ER-33
19901 Germantown Road
Germantown, MD 20874-1290
(301) 903-5707
sbir_sttr@mailgw.er.doe.gov

Business Agreements

Cost-Shared Contracts
Nonfederal parties working under DOE contract can agree to share some of the cost of developing a technology for a nonfederal market. This arrangement may involve cash, in-kind contributions, or both.

Grants and Cooperative Agreements
These contractual arrangements provide the recipient with money and/or property to support or stimulate research in areas of interest to DOE. DOE regularly publishes notices concerning grant opportunities in the *Commerce Business Daily*.

Research and Development Contracts

This acquisition instrument between the government and a contractor provides supplies and services to the government. DOE may enter directly into research and development contracts, and DOE laboratories and facilities can subcontract research and development work to the private sector. Announcements on requests for proposals are published in the *Commerce Business Daily* and are available through the EM Homepage on the Internet: *www.em.doe.gov*

Licensing Technologies

DOE contractor-operated laboratories can license DOE/EM-developed technology and software. In situations where DOE retains ownership of a new technology, the Office of General Counsel serves as licensing agent. Licensing activities are conducted according to existing DOE intellectual property provisions and can be exclusive or nonexclusive, for a specific field of use, for a geographic area, United States or foreign usage. Information on licensing technologies may be obtained by contacting the Office of Research and Technology Applications (ORTA) representatives listed later in this section.

Technical Personnel Exchange Arrangements

Personnel exchanges provide opportunities for federal or DOE laboratory scientists to work together with scientists from private industry on a mutual technical issue. Usually lasting one year or less, these arrangements foster the transfer of technical skills and knowledge. These arrangements require substantial cost-sharing by industry, but DOE has an advanced class patent agreement in place for this provision and the rights of any resulting patents become the property of the private industry participant. Contact an ORTA representative for more information.

Consulting Arrangements

Consulting arrangements are formal, written agreements in which a DOE laboratory or facility employee may provide advice or information to a nonfederal party for the purpose of technology transfer, or a nonfederal party may consult with the laboratory or facility. Laboratory/facility employees participating in this exchange of technical expertise must sign a nondisclosure agreement. Contact an ORTA representative for more information.

Reimbursable Work for Industry

This concept enables DOE personnel and laboratories to perform work for nonfederal partners when laboratories or facilities have expertise or equipment not available in the private sector. Reimbursable Work for Industry is usually termed "work for others." An advanced class patent waiver gives ownership of any inventions resulting from the research to the participating private sector company. Contact an ORTA representative for more information.

Office of Research and Technology Applications

Each federal laboratory has an Office of Research and Technology Application. These offices serve as technology transfer agents for the federal laboratories. They coordinate technology transfer activities among laboratories, industry, and universities. ORTA offices license patents and foster communication between researchers and technology customers.

ORTA Representatives:

Ames Laboratory
Todd Zdorkowski
(515) 294-5640

Argonne National Laboratory
Paul Eichemer
(708) 252-9771/(800) 627-2596

Brookhaven National Laboratory
Margaret Bogosian
(516) 344-7338

Fermilab
John Vernard
(708) 840-2529

Idaho National Engineering Laboratory
Jack Simon
(208) 526-4430

Lawrence Berkeley National Laboratory
Cheryl Fragiadakis
(510) 486-7020

Lawrence Livermore National Laboratory
Rodney Keifer (510) 423-0155
Allen Bennett (510) 423-3330

Los Alamos National Laboratory
Pete Lyons
(505) 665-9090

Morgantown Energy Technology Center
Rodney Anderson
(304) 285-4709

National Renewable Energy Laboratory
Mary Pomeroy
(303) 275-3007

Oak Ridge Institute of Science and Education
Mary Loges
(423) 576-3756

Oak Ridge National Laboratory
Bill Martin
(423) 576-8368

Pacific Northwest National Laboratory
Marv Clement
(509) 375-2789

Pittsburgh Energy Technology Center
Kay Downey
(412) 892-6029

Princeton Plasma Physics Laboratory
Lew Meixler
(609) 243-3009

Sandia National Laboratories
Warren Siemens
(505) 271-7813

Savannah River Technology Center
Art Stethen
(803) 652-1846

Stanford Linear Accelerator Center
Jim Simpson
(415) 926-2213

Westinghouse Hanford Company
Dave Greenslade
(509) 376-5601

PERIODIC TABLE

Of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110								

*Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

GPX96-0215

ACRONYMS

3-D	3-Dimensional
AIM	Automated Instrument Module
ANL	Argonne National Laboratory
CAA	Chemical Analysis Automation
CC&AT	Crosscutting & Advanced Technology
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Action ("Superfund") of 1980
CRADA	Cooperative Research and Development Agreement
D&D	Decontamination and Dismantlement, or Decontamination and Decommissioning
DAWM	Dual-Arm Work Module
DECIDE	Decision, Definition, and Evaluation
DIM	Data Interpretation Module
DoD	Department of Defense
DOE	U.S. Department of Energy
EM	Office of Environmental Management
EPA	U.S. Environmental Protection Agency
FBSC	Function-Based Sharing Control
FEMP	Fernald Environmental Management Program
GAAT	Gunite and Associated Tanks
GISC	Generic Intelligent Systems Control
HCI	Human-Computer Interface
HVC	High-Volume Concentrator
IDCS	Internal Duct Characterization System
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National Laboratory
LDUA	Light Duty Utility Arm
LLNL	Lawrence Livermore National Laboratory
MACS	Mobile Automated Characterization System
MEL	Mobile Environmental Laboratory
METC	Morgantown Energy Technology Center

MLDUA	Modified Light Duty Utility Arm
NIST	National Institute of Standards and Technology
ORNL	Oak Ridge National Laboratory
ORTA	Office of Research and Technology Applications
OST	Office of Science and Technology
OTD	Office of Technology Development
OU	Operable Unit
PDCU	Power Distribution Control Unit
PNNL	Pacific Northwest National Laboratory
POTS	Position Orientation Tracking System
PRDA	Program Research and Development Announcement
R&D	Research & Development
RACS	Reduced Access Characterization Subsystem
RCRA	Resource Conservation and Recovery Act
ROA	Research Opportunity Announcement
RTAF	Robotics Technology Assessment Facility
RTDP	Robotics Technology Development Program
SAM	Standard Analysis Method
SBIR	Small Business Innovation Research
SERS	Selective Equipment Removal System
SLM™	Standard Laboratory Module™
SNL	Sandia National Laboratoriy
SPCS	Small Pipe Characterization System
SRTC	Savannah River Technology Center
TMADS	Tether Management and Deployment System
TSC	Task Sequence Controller
TTP	Technical Task Plan
TWR	Tank Waste Retrieval
UST	Underground Storage Tank
VCE	Virtual Collaborative Environment
WHC	Westinghouse Hanford Company