

— February 1994

Technology Summary

Robotics Technology Development Program

Office of Technology Development
Office of Environmental Management



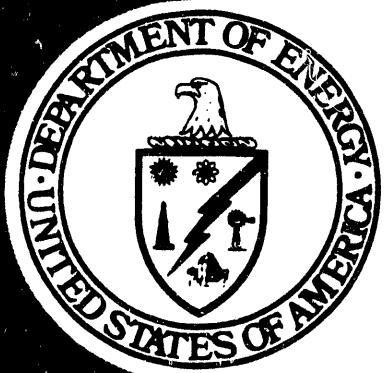
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Office of Environmental Management
Office of Technology Development

Robotics Technology Development Program

Technology Summary

MASTER

February 1994

ROBOTICS TECHNOLOGY DEVELOPMENT PROGRAM

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OFFICE OF TECHNOLOGY DEVELOPMENT OVERVIEW

The Department of Energy (DOE) established the Office of Technology Development (EM-50) (OTD) as an element of Environmental Restoration and Waste Management (EM) in November, 1989 (see Figure A). The organizational structure of EM-50 is shown in Figure B.

EM manages remediation of all DOE sites, as well as wastes from current operations. The goal of the EM program is to minimize risks to human health, safety and the environment, and to bring all DOE sites into compliance with Federal, state, and local regulations by the year 2019. EM-50 is charged with developing new technologies that are safer, faster, more effective and less expensive than current methods.

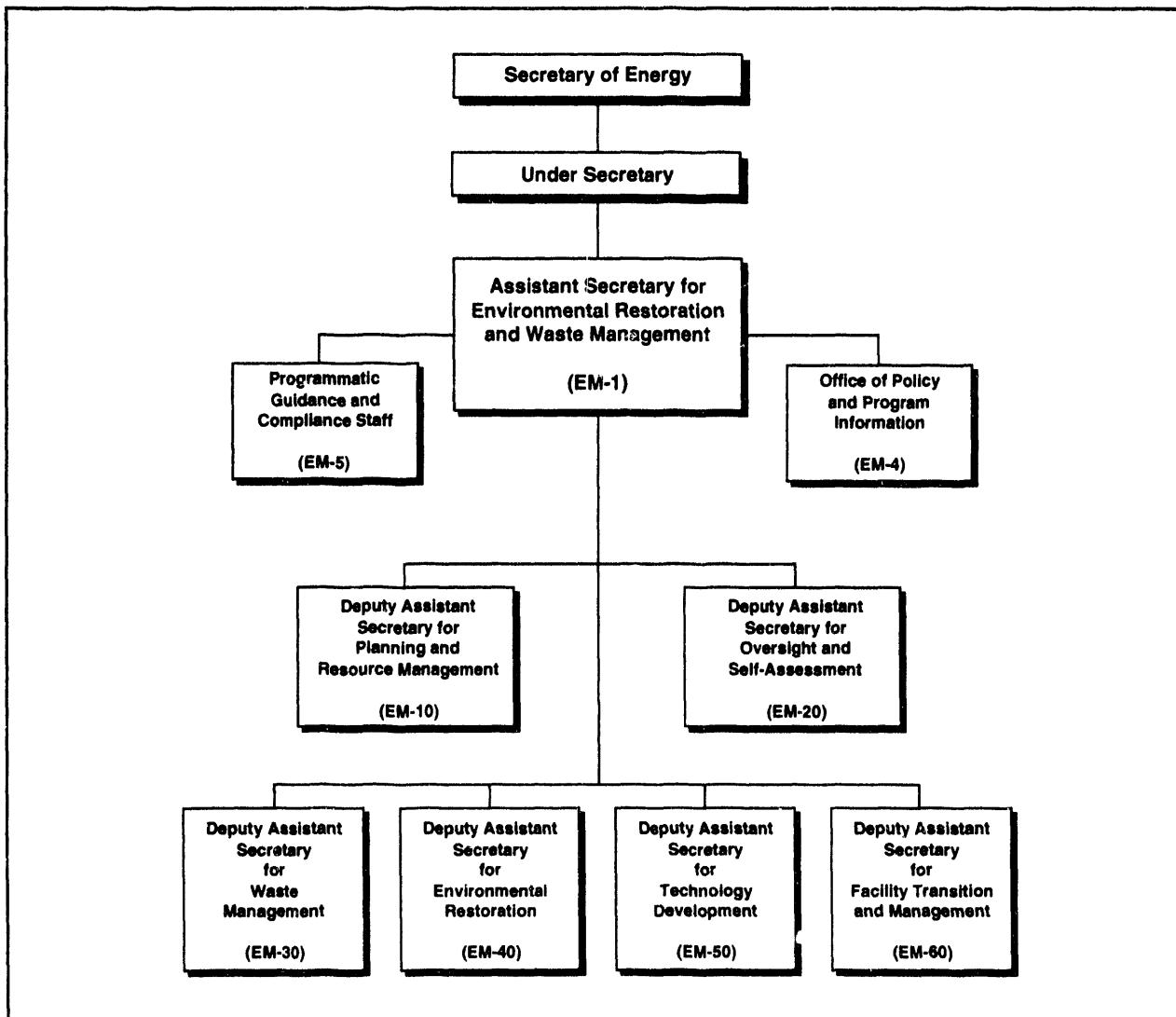


Figure A. DOE Organizational Structure as of June 1993.

In an effort to focus resources and address opportunities, EM-50 has developed **Integrated Programs (IP)** and **Integrated Demonstrations (ID)**.

An *Integrated Program* is the cost-effective mechanism which assembles a group of related and synergistic technologies to evaluate their performance to solve a specific aspect of a waste management or environmental problem, and it can be either unique to a site or common to many sites. An Integrated Program supports applied research to develop innovative technologies in key application areas organized around specific activities required in each stage of the remediation process (e.g., characterization, treatment, and disposal).

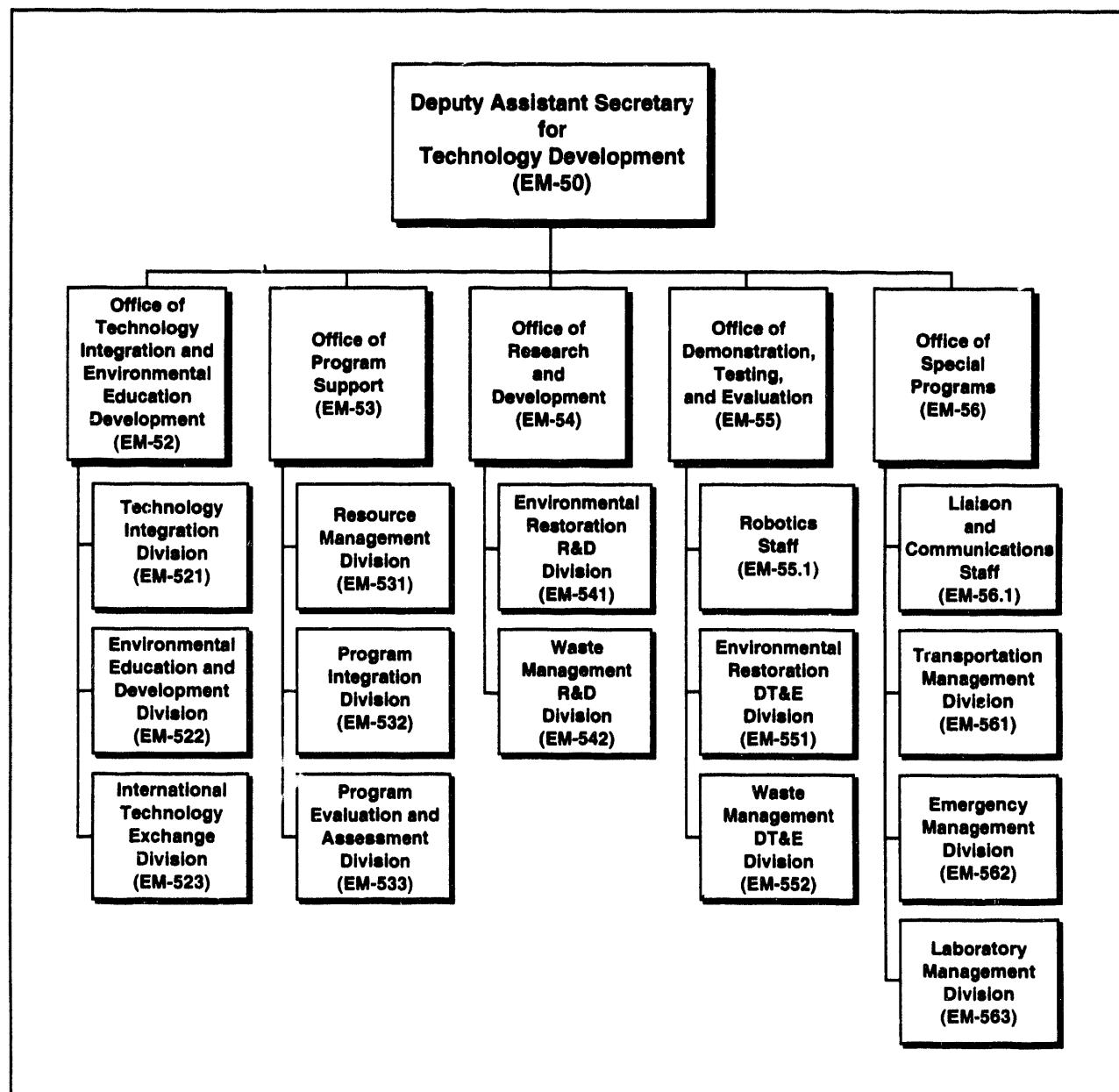


Figure B. Office of Technology Development Organizational Structure as of June 1993.

The *Integrated Demonstration* is the cost-effective mechanism that assembles a group of related and synergistic technologies to evaluate their performance individually or as a complete system to correct waste management and environmental problems from cradle to grave.

The Robotics Technology Development Program (the subject of this report) is a staff office attached to EM-55, the Office of Demonstration, Testing, and Evaluation.

ROBOTICS TECHNOLOGY DEVELOPMENT 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 Restoration and Waste Management (EM) Programs resulted in a clear understanding of needed robotics applications toward resolving definitive 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), Contaminant Analysis Automation (CAA), Mixed Waste Operations (MWO), and Decontamination & Dismantlement (D&D). The RTDP Group realized that much of the technology development was common (Cross Cutting-CC) to each of these robotics application areas, for example, computer control and sensor interface protocols. Further, the OTD approach to the Research, Development, Demonstration, Testing, and Evaluation (RDDT&E) process urged an additional organizational break-out between short-term (1-3 years) and long-term (3-5 years) efforts (Advanced Technology-AT). The RTDP is thus organized around these application areas - TWR, CAA, MWO, D&D and CC&AT - with the first four developing short-term applied robotics. An RTDP Five-Year Plan was developed for organizing the Program to meet the needs in these application areas.

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 a team of experts chosen from throughout the DOE Complex, private industry and universities: an integrated, multi-member, team approach.

The DOE Headquarters Robotics Program Manager, a DOE employee, is responsible for higher level management of the entire Program through consultations throughout EM and frequent interactions with Coordinators. Overall program direction, as reflected in fiscal emphasis, is a primary responsibility. Another is program integration among several RTDP application areas, various OTD activities supported by the RTDP, and non-OTD offices in EM. Program integration is critical for resource maximization in meeting needs. The Robotics Program Manager's function can summarily be stated as directly managing the RTDP so as to develop and demonstrate efficacious robotics systems, defined as needed by the supported 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 supported programs to build required systems.
- 4) EXTERNAL INTEGRATION - each part of the RTDP is directly mapped onto DOE Headquarters organization.

- 5) INTERNAL INTEGRATION- emphasis on solutions to common problems within the RTDP for application to supported programs.
- 6) NATIONAL PERSPECTIVE - address complex-wide solutions through direct management by DOE Headquarters.

A brief description of each Technical Application Area appears below, with an elaboration of each area in subsequent sections of this book.

Tank Waste Retrieval (TWR): Storage Tank characterization and retrieval using long-reach robot manipulators. RTDP 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.

Contaminant Analysis Automation (CAA): The CAA Team develops fully automated modules which perform a generic task 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.

Mixed Waste Operations (MWO): The MWO Team develops systems for front-end handling and pre-processing of mixed waste containers and contents, plus handling of the final waste forms after processing. Automated inspection of stored waste containers is also a major aspect of the MWO group. Graphical modeling and automation of operations with graphics viewing is a key approach to facilitating operations programming.

Decontamination and Dismantlement (D&D): The D&D Group works on automating the D&D process, from surveillance to facility characterization to surface decontamination to hot cell dismantlement 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.

Cross Cutting & Advanced Technology (CC&AT): The CC&AT Group develops technologies used throughout the RTDP. Projects are directed toward a generic, graphics 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 clean-up systems.

The Robotics Technology Development Program is discussed in detail in the following chapters and includes specific points of contact. Central point of contact for the Program is:

Dr. Linton W. Yarbrough
Robotics Program Manager
U. S. Department of Energy
Washington, D.C. 20585-0002
(301) 903-7293

OFFICE OF TECHNOLOGY DEVELOPMENT ROBOTICS PROGRAM COORDINATORS

Linton W. Yarbrough II, PhD
Robotics Program Manager
Trevion II/Suite 400
U.S. Department of Energy
Washington, D.C. 20585-0002
FON/FAX: (301) 903-7293/7234
EMail: morgan%em-04@mailgw.er.doe.gov

Ray Harrigan, PhD SNL
Cross Cutting & Advanced Technology Coordinator
Sandia National Laboratories
Department 2102, MS0949
P.O. Box 5800
Albuquerque, NM 87185-0949
[1515 Eubank, SE (Xpress Mail)]
Albuquerque, NM 87123
FON/FAX: (505) 844-3004/6161
EMail: harrigan@isrc.sandia.gov

William Hamel, PhD ORNL
Decontamination and Dismantlement Coordinator
Oak Ridge National Laboratory
P.O. Box 2008
Building 7601
Oak Ridge, TN 37831-6304
FON/FAX: (615) 574-5691/576-2081
U of Tenn FON/FAX: 615-974-6588/5274
EMail: whh@ornl.gov

Robert Hollen LANL
Contaminant Analysis Automation Coordinator
Los Alamos National Laboratory
P.O. Box 1663, MS J580
Los Alamos, NM 87545
FON/FAX: (505) 667-3186/665-3911
EMail: hollen@esa.lanl.gov

Dave Bennett
Tank Waste Retrieval Coordinator
Battelle/Pacific Northwest Laboratory
K-17 P.O. Box 999
Richland, WA 99352
FON/FAX: (509) 375-2159/372-4725
EMail: dw_bennett@pnl.gov

Clyde Ward SRTC
Mixed Waste Operations Coordinator
Westinghouse Savannah River Company
Building 773-A, D-1134
Aiken, SC 29808
FON/FAX: (803) 725-5891/7369
EMail: cward@srs.gov

Bruce Wilding, WINCO
INEL Site Representative
P.O. Box 4000, MS 3765
2525 Freemont Street, EROB 138
Idaho Falls, ID 83403-5104
FON/FAX: (208) 526-8160/8939
EMail: wilding@pmafire.inel.gov

Ernz Grasz
LLNL Site Representative
Lawrence Livermore National Laboratory
P.O. Box 808 L-591
Livermore, CA 94550
FON/FAX: (510) 423-6556/423-4606
Pager: 510-423-2497/02130
EMail: grasz1@llnl.gov

Don Herman, FERMCO
Fernald Site Representative
P.O. Box 398704
MS-81-2, Technology
[25 Merchant St., 45246 (Xpress Mail)]
Cincinnati, OH 45239-8704
FON/FAX: (513) 648-6555/6915

Robotics Tank Waste Retrieval

Section 1.0

1.0 ROBOTICS TANK WASTE RETRIEVAL OVERVIEW

The Tank Waste Retrieval (TWR) Team provides a cost-effective robotics technology base for retrieval of waste from underground storage tanks. Led by Pacific Northwest Laboratory, with contributions from Oak Ridge National Laboratory and Sandia National Laboratories, this three-laboratory Team works closely with industry and universities to meet program objectives.

The TWR Team provides enhanced research and development tools centered around a robotics test bed and a comprehensive computer-based simulation network shared among the three contributing laboratories. Retrieval-focused robotics technologies are developed by the Team and integrated as part of the test bed for demonstration. The Team directly responds to technology needs identified by waste tank remediaters and provides robotics technology inputs for tank remediation planning and procurements.

1.1 ROBOTICS DEVELOPMENT TEST BED SYSTEM

TASK DESCRIPTION

Robotics Tank Waste Retrieval (TWR) provides a cost-effective robotics technology base for retrieval of waste from underground storage tanks. The purpose of this thrust, as an increment of TWR Robotics, is to provide tank waste retrieval design and evaluation tools, centered around a full-scale robotics test bed and a highly capable computer-based simulation system.

Test Bed: The robotics test bed is a full-scale, comprehensive development facility for the evaluation of new manipulator-based retrieval technologies (see Figure 1.1). The test bed provides for development, testing and demonstration of waste retrieval methods, equipment and procedures. The test bed plays a crucial part in the validation of simulation codes that are provided as another tool in this effort. The test bed, large portions of which are

being procured from commercial industry, will be fully operable in FY96.

Simulation: A high-fidelity simulation capability is provided as part of this thrust that enables rapid evaluation of vendor designs and development concepts. The simulator also provides for extrapolation of test data retrieved from the test bed and other experimental resources to match scale and configurations of planned retrieval systems.

The simulation capability is distributed among the three contributing laboratories and is connected by a high speed digital link.

TECHNOLOGY NEEDS

The robotics test bed and simulation capabilities fill needs for sophisticated design and evaluation tools to support planned retrieval actions. Capability for integrated testing of all robotics-based aspects of waste retrieval is required. Newly conceived methods must be tested and demonstrated as an increment of a robotic system.

Simulation provides the ability to rapidly define parametric relationships in processes and controls. With this preview, the range of parameter values selected for actual testing can be much smaller, thereby improving the productivity of the development cycle immensely. Further, simulation permits timely evaluation of designs produced either by the development team or vendors.

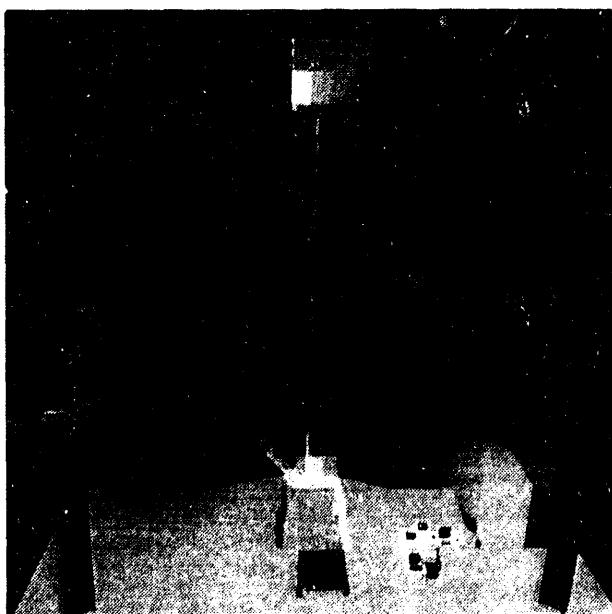


Figure 1.1. Tank Waste Retrieval Test Bed.

ACCOMPLISHMENTS

The robotics test bed comprises commercially available, standard robotic systems. These devices are useful for:

- first assessments of functionality of generic, very large robotic systems;
- testing and demonstration of new concepts for control of large, physically flexible manipulator links;
- testing and demonstrating new concepts for graphical supervisory control; and
- initial testing and demonstration of waste retrieval end effectors.

Each of the three contributing laboratories has invested in stand-alone simulation and modelling capability, which include kinematic and dynamic modelling of proven merit in evaluating potential configurations for the robotic test bed. Other analyses have been performed as a basis for the reference design of a waste retrieval system to be used at Hanford, Washington.

COLLABORATION/TECHNOLOGY TRANSFER

The new test bed, to be fully implemented in FY96, is presently being procured. Specifications have been prepared and contracting activities are underway. The new test bed provides a robotic development and demonstration environment that is fully typical of robot configurations to be later employed in tank waste retrieval.

Enhanced simulation capability is presently being sought. Purchase specifications are being prepared for simulation and modelling

software for each of the three laboratories. The enhanced simulation stations and data link will be in place and functional by the end of FY94.

The new simulation capability will include process and controls modelling, queuing modelling as well as kinematic and dynamic models. Connecting the simulation capabilities via a high-speed data link among the three laboratories will provide the ability to share real-time simulations as well as to drive test bed operations remotely from any of the three labs.

For further information, please contact:

Dave Bennett
TWR Coordinator
Battelle/Pacific Northwest Laboratory
509-375-2159

William Hamel, PhD
D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

Ray Harrigan, PhD
CC&AT Coordinator
Sandia National Laboratories
(505) 844-3004

1.2

TECHNOLOGY DEVELOPMENT

TASK DESCRIPTION

The purpose of this thrust is to perform research, development and demonstration supporting manipulator-based tank waste retrieval, utilizing the tools provided in Thrust 1. Research, development and demonstration provide a performance baseline for components and integrated retrieval systems while providing specific retrieval solutions and methods addressing practical needs. Work is performed collaboratively by three national laboratories, associated universities and industry.

TECHNOLOGY NEEDS

Multiple robotics technology needs have been defined in collaboration with tank waste remediaters. Each need forms the basis for a development task.

Existing openings in underground waste storage tanks are limited in size. Manipulator payload and reach requirements dictate significant mechanical flexibility, both static and dynamic, that must be mitigated. Accomplishments to date include development of active and passive methods to damp vibrations in long reach manipulators. These approaches have been tested successfully on simplistic manipulator geometries. Many potential kinematic arrangements for waste retrieval manipulators have been investigated to ascertain optimal configuration for waste retrieval and maximum stiffness.

Improved capabilities in teleoperation (man-in-the-loop) and robotic (autonomous) opera-

tion are needed. During waste retrieval operations, it is required to remotely supervise and direct large manipulators. Highly productive man-in-the-loop operations must be available that include an accurate and complete perception of the work space for the human operator. Autonomous (robotic) control modes must also be selectable for performance of routine, repetitive actions. Autonomous functions also are needed to oversee actions of the operator, limiting these actions to avoid unsafe conditions, such as collisions.

Significant improvements in man-machine-interface have been achieved through development and demonstration of a graphic-based supervisory control system. Mapping sensors have been demonstrated that provide a three-dimensional digital image of the tank work space. The graphical control system can access the image and the autonomous manipulator controller to plan tool paths and avoid collisions in the tank.

Needs also have been identified to improve reliability and productivity of complex mechanical systems operating in the hostile in-tank environment. For example, the environment includes high radiation, hazardous and corrosive chemicals, high moisture, high temperature and airborne dirt. Improvements are being sought in equipment decontamination and maintenance, reliable cable and hose management, and cost effective power and data transmission capabilities.

Also needed are improved waste retrieval methods that are compatible with tank access constraints, various waste morphologies and safety requirements. Waste dislodging devices

are required to be configured as end-of-arm tooling (end effectors) for the retrieval manipulator. Since more than one waste form is present in any given tank, an ability to remotely change end effectors during a waste retrieval operation is needed.

ACCOMPLISHMENTS

To date, many of the robotics-based retrieval technologies described here have been developed and demonstrated individually. The next step is to combine these developments and evaluate their performance as increments of a complete retrieval system. To accomplish this, the robotics test bed will be utilized to maximum benefit. Plans are to integrate these advanced technologies into the test bed, perform evaluations and provide the results to waste tank remediaters and industry.

A complete waste retrieval end effector development and demonstration program is currently being planned that will utilize parametric data regarding performance of basic waste retrieval methods to produce test and prototype equipment. These devices will be evaluated in the robotics test bed and the designs provided to industry.

COLLABORATION/TECHNOLOGY TRANSFER

Cooperative Research and Development Agreements (CRADAs) have been established in several technology subtasks. Work is ongoing with commercial industry to improve dynamic stability of large manipulator components through active control and passive methods.

Two CRADA partners involved in the TWR technology development arena include Schilling Development, Inc., for their teleoperated control methods for Flexible Link Manipulators, and CIMCORP, for their telescoping mast technology.

For further information, please contact:

Dave Bennett
TWR Coordinator
Battelle/Pacific Northwest Laboratory
509-375-2159

William Hamel, PhD
D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

Ray Harrigan, PhD
CC&AT Coordinator
Sandia National Laboratories
(505) 844-3004

Robotics Contaminant Analysis Automation

Section 2.0

2.0

ROBOTICS CONTAMINANT ANALYSIS AUTOMATION

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 characterized to determine the elemental, isotopic, and compound content before remediation can begin. It is projected that sampling requirements will necessitate generating more than 10 million samples

by 1995, which will far exceed the capabilities of current manual chemical analysis laboratories. The Contaminant Analysis Automation Team (CAA) is designing and fabricating robotic systems that will standardize and automate both the hardware and software of the most common environmental chemical methods. The CAA Team was formed in early 1990 to identify those analysis methods needing attention quickly, and to define standards of modularity that would make reconfiguration

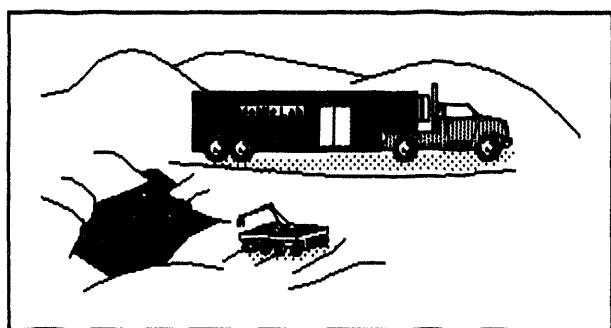
Figure 2.0. On-site Sample Analysis.

and operation of these automated systems intuitive. Two of the EPA methods were identified for initial automation: EPA Method 3540 (the Soxhlet soil extraction) and EPA Method 3550 (the Sonication soil extraction). Both of these methods are designed as organic analyte sample preparation methods. No current automated commercial systems were available to automate these methods.

Initial discussions revealed that modularized and standardized chemistry (within both the software control and the hardware) were necessary if these automated systems were to be useful and transportable. The concept of on-site sample analysis is shown in Figure 2.0.

To provide valid data and timely sample analysis results, the Team realized that it would be necessary to harden these systems so they could be transported directly to the remediation site. Another factor leading toward the modularity concept was the need for systems, which, leveraging standardization, could be configured by a knowledgeable chemist for a specific method and yet could be operated by a technician not versed in environmental chemistry.

Los Alamos National Laboratory is the lead laboratory in the CAA coordination area. Other laboratories involved in the CAA effort include Pacific Northwest Laboratory, Idaho National Engineering Laboratory, Sandia National Laboratories, and Oak Ridge National Laboratory. The CAA thrust is to address the development of technologies necessary for the automation of DOE and DOE-contract environmental laboratories. This effort is in response to the tremendous demand for chemical characterization of soil samples, contents of storage tanks, and water samples that must take place before remediation can begin.



2.1

THE STANDARD LABORATORY MODULE AND STANDARD ANALYSIS METHOD

TASK DESCRIPTION

By designing and transferring to industry systems based upon the Standard Analysis Method (SAM) architecture, the CAA group is working toward 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 Project is also a highly collaborative effort among engineering teams in five DOE National Laboratories. In addition, several Standard Library Module (SLM) manufacturers will be either directly contracted or engaged for SLM development via a CRADA involving one of the CAA-member National Laboratories.

The CAA concept allows the chemist to assemble an automated environmental analysis system using standardized modules easily without the worry of hardware or software incompatibility or necessity of generating complicated control programs. Hardened for the

rigors of on-site remediation, these systems will be designed for use within transportable laboratories directly at a remediation site.

TECHNOLOGY NEEDS

Accomplishing CAA goals and missions required conceiving the SAM. A graphical representation of the SAM concept is shown in Figure 2.1.

The SAM is a glovebox-compatible grouping of subunits into a system that will automate current analysis technologies. These subunits behave like modular building blocks. The SAM will accept samples from the field as input. After automated sample preparation, the samples will be analyzed and the resulting raw data will be automatically interpreted by an expert system. The knowledge of the waste site generated by the SAM is then used for remediation. Each SAM 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. Making use of modular, open-architecture software allows the human-computer interface to be much more intuitive and facilitates the addition of new or different system capabilities. The SAM concept comprises Standard Preparation Modules (SPM), an

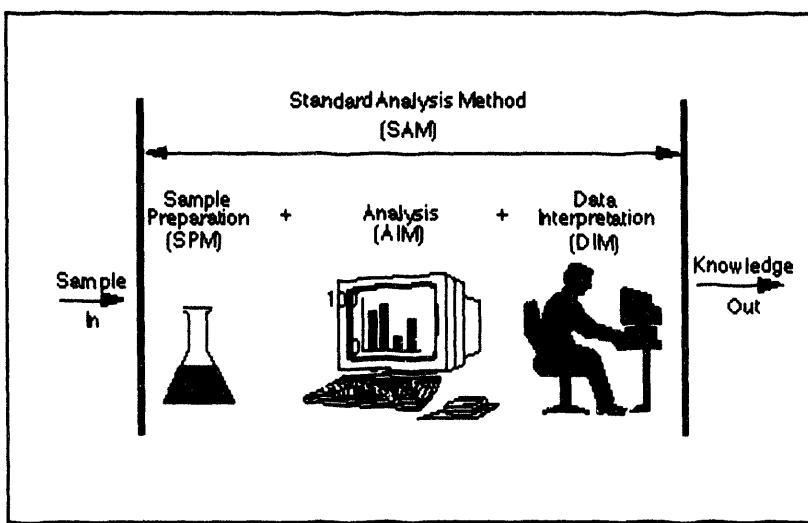


Figure 2.1. Standard Analysis Method (SAM) Concept.

Analytical Instrumentation Module (AIM), and a Data Interpretation Module (DIM). One advantage of the modular SAM concept is its capability to accommodate emerging technologies. This capability results from the flexibility of the standardized hardware and software.

ACCOMPLISHMENTS

Based on a DOE needs survey, EPA organic methods 3540 (Soxhlet Extraction) and 3550 (Sonication Extraction) were chosen as the targets for initial automation. The SLMs for the Soxhlet procedure were developed by Pacific Northwest Laboratory, and the SLMs for the Sonication procedure were developed by Los Alamos National Laboratory. The common SLMs, shared between these methods have been engineered by Idaho National Engineering Laboratory, which has completed the Drying-Column SLM and the Gel Permeation Chromatograph SLM. These units were demonstrated in an integrated, hood enclosed system in March 1992 at the INEL. Two Hewlett Packard (HP) ORCA™ rail-mounted robots were used to move samples between the SLMs and a HP gas chromatograph to demonstrate the concept of the automated environmental analysis laboratory. The benchtop is a rectangular geometry and can be located inside existing laboratories. A four-meter long, hooded enclosure contains the system, providing ventilation for the solvents used. Pre-weighed samples enter the system in glass beakers and are shuttled from SLM to SLM by the robots. When a sample has completed the preparation steps from extraction through gel permeation chromatography cleanup, it is placed in autosampler queue of the gas chromatograph for analysis.

Fully functioning prototype SAMs for EPA's 3540 and 3550 are scheduled to be in place, ready for EPA method validation, by late 1994.

The CAA Team is also currently developing SLMs for the inorganic metals methods in the

SW-846 3500 series. A sample preparation SLM, a microwave digestion SLM, and a filtration SLM are under development. Additionally, an automated hot plate digestion SLM concept is under evaluation.

COLLABORATION/TECHNOLOGY TRANSFER

This Team has structured a large and innovative Technology Transfer Plan, based on DOE Headquarters involvement, to accomplish the commercialization of developed prototype systems. This plan provides for partnering with an industrial system integrator to provide SAM systems to DOE customers, maintenance, documentation, user training and support. The transfer plan also includes partnering through CRADAs and contracts with instrumentation companies for engineering and producing SLMs.

To date, CRADAs with ABC Laboratories, Throughput, Varian, Lockheed, and Neuralware have been executed. Additionally, the CAA program is pursuing several more CRADAs for new SLMs.

For further information, please contact:

Robert Hollen
CAA Coordinator
Los Alamos National Laboratory
(505) 667-3186

Tracy Erkkila
Alternate CAA Coordinator
Los Alamos National Laboratory
(505) 665-2754

2.2

AUTOMATED SYSTEM SOFTWARE

TASK DESCRIPTION

This task will develop system software to operate a fully automated chemistry bench for the CAA Project. This includes the development of a Task Sequence Controller (TSC), a Database, and Human Computer Interface (HCI). All software modules in the CAA project are designed to be plug-and-play, and are therefore object-oriented, facilitating modularization, maintainability, reusability, flexibility, and extensibility. The C++ language is being used to develop the TSC and SLM controllers. The database is being developed using the C++ based object-oriented database tool, ONTOS. The HCI is being developed in G2, a real-time, object-oriented expert system tool. The architecture of the CAA system software is shown in Figure 2.2.

In order to achieve the goal of plug-and-play among modules, very specific standards for communication and control are under development, and include a generic client-server interface built with GENISAS, an interface package developed by Sandia National Labo-

ratories. This standard interface ensures that all modules conform to specific process state behavior and can be controlled with a set of standard commands.

The controllers for the SLMs perform real-time control of the chemistry hardware, and provide feedback for single point, supervisory control. This supervisory control is accomplished in the TSC, which is a script-based, event driven controller modeled after advanced controllers in manufacturing environments. The TSC performs resource allocation and management and process monitoring. In addition, the TSC will be able to perform discrete event simulation. This simulation capability will enable laboratory operators to play "what-if" scenarios with their laboratory setup. For instance, one could measure the change in throughput caused by a re-arrangement of the laboratory SLMs or the introduction of one or more redundant SLMs without actually acquiring the SLM hardware.

The database module is a distributed, C++ based, object-oriented database management system (DBMS) with internal client/server capabilities that permit data storage on different devices. An external user interface will enable the analytical chemist to browse through the database and select data for analysis. Database functionality is defined by the information needs of laboratory system setup and initialization, sample tracking, system maintenance, and data analysis. Sufficient data must be stored to legally support the analytical results.

The database design was based on the Analytical Data Interchange and Storage Standards (ADISS) constructs and the Consortium on

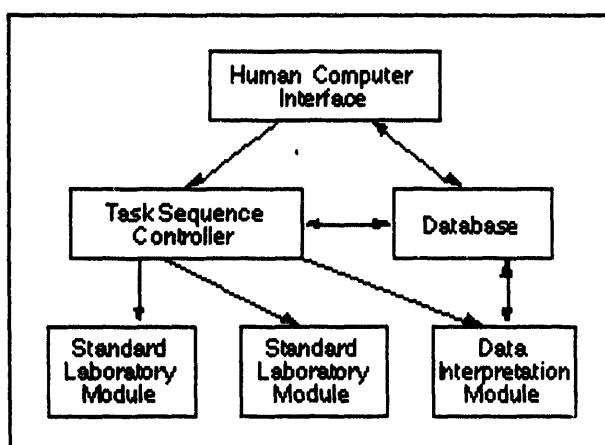


Figure 2.2. Contaminant Analysis Automation Software Architecture.

Automated Analytical Laboratory Systems (CAALS) Modularity and Data Communications Standards. Modifications support CAA hardware components, provide easy waste tracking, and supply additional information necessary for the fully automated system.

The HCI provides an easy-to-use graphical user interface to a CAA laboratory for monitoring, control, and information access. The HCI is designed as a set of G2 knowledge bases built of objects, classes, attributes, variables and parameters, rules, procedures, formulas, connections and relations. Screens, icons, push-buttons, scrolling lists, etc. are also available. Rules and procedures are used to drive the dynamics of the HCI.

The HCI consists of four pieces:

- general facilities;
- process monitoring;
- configuration management; and
- Quality Assurance/Quality Control

General facilities provided are communications with the database and TSC, access controls for different levels of users, alarm and message handling, reporting, find, and help. Process monitoring is the main part of the HCI, which provide laboratory monitoring, sample entry and control, TSC status and control, high-level SLM status and control, detailed SLM control, performance monitoring, waste stream tracking, and consumables status. Configuration management editors allow chemical methods, SLM, and laboratory bench additions and modifications to be made. Quality Assurance/Quality Control provides an environment for viewing data collected during CAA operation.

TECHNOLOGY NEEDS

The goal of plug-and-play modules in an automated system requires standardization of interfaces and control sequences. A TSC is required to efficiently control an automated laboratory in this manner.

Permanent information storage is necessary for start-up and archiving for quality control, quality assurance, and data analysis. A centralized database is an efficient information repository and will provide the opportunity to explore the information requirements for efficient automation.

An easy-to-use graphical HCI is necessary for the efficient operation of an automated laboratory.

ACCOMPLISHMENTS

- An initial draft of standards for communication and control between software modules and SLMs has been developed by the CAA project.
- The TSC is under development with minimum functionality being tested with software simulators for other modules. This minimum functionality includes script processing, sample transportation, and inter-module communication.
- The database objects have been designed based on the ADIIS constructs internal CAA requirements. A connection established with the GENISAS server allows storing, retrieving and deleting data. The prototype database is usable for a set of classes for testing interactions with the HCI and TSC. The database

has the capacity to respond to inquiries using Object SQL. Development is continuing to expand capabilities as required by the TSC, HCI, and DIM.

- A testing HCI was developed previously for debugging and demonstrating SLM hardware and software. The testing HCI is being used during SLM chemical validation.
- The HCI for the fully integrated system is under development. An evolutionary approach is being followed, starting with minimal functionality. Currently, work is being concentrated on process monitoring.

For further information, please contact:

Michael Griesmeyer
CAA Task Sequence Controller
Sandia National Laboratories
(505) 844-0281

Patricia Medvick
CAA Database
Los Alamos National Laboratory
(505) 667-2676

Susan Mniszewski
CAA Human Computer Interface
Los Alamos National Laboratory
(505) 667-0790

COLLABORATION/TECHNOLOGY TRANSFER

Collaboration on communication and control standards with the Consortium on Automated Analytical Laboratory Systems (CAALS) is in progress.

The CAA Program is also pursuing CRADA collaboration with other software companies.

TASK DESCRIPTION

The Contaminant Analysis Automation Program is developing laboratory automation in a SLM format. One of the goals of the CAA project is to provide both an automated analytical instrument module (AIM) and an automated data interpretation module (DIM) in 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.

The target for the demonstration of automated analysis and automated data interpretation is EPA Method 8080, for organochlorine compounds and poly-chlorinated biphenyls (PCBs). A gas chromatography (GC) instrument is incorporated into the automated laboratory and explores the automated interpretation of the chromatograms generated from each sample. Method 8080 is used to detect and quantitate Aroclors. Aroclors are 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. As illustrated in Figure 2.3, the

complexity of the chromatogram often inhibits the identification and quantification of the sample components.

Pattern recognition tools will be used in the automated analysis to replace the intuitive pattern recognition performed in manual data interpretation. These techniques will identify peak patterns from Aroclor PCB mixtures in the complex chromatograms of environmental samples. Standard pattern recognition methods will alleviate the inefficiency and lack of uniformity that result from subjective data interpretation decisions by a human expert. Current development includes principal component analysis, multiple linear regression, correlation, and neural network pattern recognition analysis methods.

The pattern recognition results will be interpreted in an expert-system-driven DIM, and expert-level rules and procedures will be incorporated into the expert system DIM that will draw conclusions and provide confidence measurements from the data processing results. The DIM will have two operational

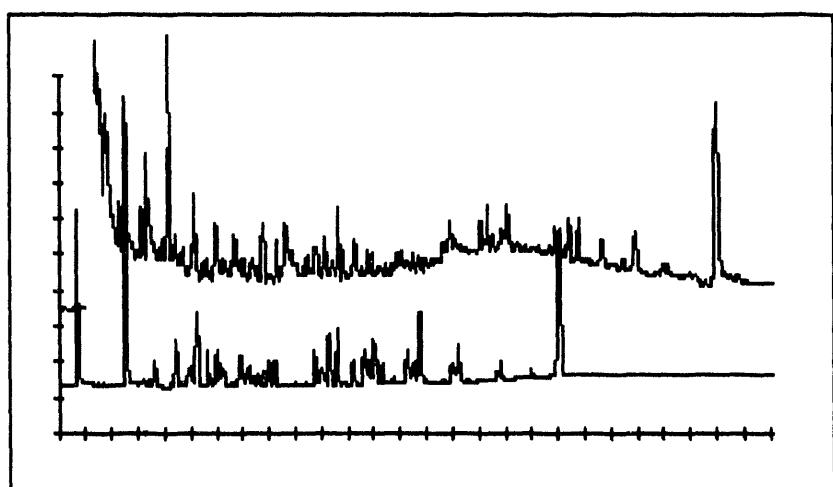


Figure 2.3. Gas chromatograms from an environmental sample and an Aroclor standard.

modes, an on-line mode that performs data analysis and is controlled by the automation controller via the SLM protocols, and an off-line mode that provides the analytical chemist with the tools required to build automated data analysis methods and review raw data and analysis process. Other tasks required of the DIM include integrity validation of the raw data, feedback of information to the TSC to assure proper sample processing, automated quality control and quality assurance functions, and an interface to the laboratory database.

The data interpretation expert system will be developed in a standard format. Other analytical instruments will be incorporated into the automated laboratory and the techniques for analyzing their data integrated into the DIM. In addition to the GC, automated data analysis is being developed for gas chromatography/mass spectrometry instruments and atomic absorption spectroscopy instruments.

ACCOMPLISHMENTS

- To test and demonstrate pattern matching calibration model concepts, a typical calibration data set for the simultaneous analysis of Aroclors 1242, 1254 and 1260 according to EPA SW-846 Method 8080 were acquired. These Aroclors were selected because they were the primary mixtures sold and because state-of-the-art separations technology does not resolve all of the PCB structural isomers or congeners. This data set has been used to test principal component analysis pattern recognition.
- A principal component analysis of the Aroclor calibration data set was completed. The standard deviation of the Aroclor 1254 calibration function is 18 ppb. Essentially identical results were obtained for the other two Aroclors. The results clearly indicate that data interpretation techniques based upon pattern matching concepts can be implemented.
- Multiple linear regression, correlation, and neural network pattern recognition analysis has been applied to the Aroclor data. The expert system DIM draws upon the different strengths of the method suited to synthesize the final result.

TECHNOLOGY NEEDS

There are several demonstrations of pattern recognition techniques applied to data analysis. However, no analytical methods have been developed for routine use in environmental laboratories. In this project, 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.

COLLABORATION/TECHNOLOGY TRANSFER

Participants in the data interpretation automation effort include:

Jamie L. Ferguson

Idaho National Engineering Laboratory

Leon N. Klatt

Oak Ridge National Laboratory

Wesley P. Unruh

Glen R. Magelsson

John R. Zahrt

Susan M. Mniszewski

Los Alamos National Laboratory

Academic collaborators:

Martin Stillman

University of Western Ontario

Mark Krahling

University of Wisconsin - Eau Claire

Industrial collaborators:

Lockheed Missiles and Space Company

Varian Chromatography Systems Inc.

NeuralWare Inc.

For further information, please contact:

John Elling

CAA Automated Data Interpretation

Los Alamos National Laboratory

(505)665-3047

[REDACTED]

CHEMICAL VALIDATION OF STANDARD LABORATORY MODULES

TASK DESCRIPTION

The CAA Program is developing Standard Laboratory Modules (SLM's) 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 the Environmental Chemistry Group at Los Alamos National Laboratory working for the Laboratory Managers Division of DOE EM-50. Validation of the individual SLMs will verify that:

- analytical data generated by the automated system are consistent with data generated by manual methods;
- individual SLM's are capable of achieving the analytical requirements of trace environmental analysis; and
- SLM's are able to withstand the rigors of automated environmental analysis.

Analytical data which must be consistent with manual data include:

- method detection limits;
- surrogate recoveries;
- matrix spike and spike duplicate recoveries; and
- recoveries of spiked compounds from quality control samples.

In order 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 and maintenance, and sample throughput must also be evaluated before the final production of modules.

In order to evaluate the criteria outlined above, the Environmental Chemistry Group at Los Alamos National Laboratory has 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 SLM's in terms of the adequacy of the data generated, the mean time between failures, and the mode of failure.

TECHNOLOGY NEEDS

One estimate of the future need within DOE and the Department of Defense (DoD) is given by 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 which could result in significant cost savings.

ACCOMPLISHMENTS

- The Sonication and Drying Column SLMs have been chemically tested and validated. Detailed reports for these two modules are being compiled.
- The Gel Permeation and Soxhlet SLMs are currently undergoing chemical testing and validation.
- The chemists from the Environmental Chemistry Group are working with the Idaho National Engineering Laboratory on a High Volume Concentrator SLM and a Filtration SLM.
- Work is also ongoing with the Oak Ridge National Laboratory on the Microwave Digestion SLM.
- The Environmental Chemistry Group is providing support to the CAA Program's Data Interpretation Module Working Group as well as the Human Computer Interface Group.

COLLABORATION/TECHNOLOGY TRANSFER

During the validation of each of the SLM modules, the Environmental Chemistry Group is collaborating with the design team responsible for the fabrication of the SLM. Innovations and suggestions that are developed within EM-9 are transferred to the CAA Program.

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

For further information, please contact:

Matthew Monagle
CAA Chemical Validation
Los Alamos National Laboratory
(505) 667-5889

Craig Leasure
CAA Chemical Validation
Los Alamos National Laboratory
(505) 667-3269

2.5 TECHNOLOGY TRANSFER IN THE CAA PROJECT

TASK DESCRIPTION

The Contaminant Analysis Automation Program consists of an aggressive team developing automated sample analysis systems for the DOE. This team is structuring a large and innovative Technology Transfer Plan, based on DOE Headquarters involvement, to accomplish the commercialization of developed prototypical systems (see Figure 2.5).

These integrated systems will be necessary for the rapid, cost-effective, and accurate chemical characterization of governmental remediation projects. The effective transfer of this technology into the automation marketplace for manufacture and commercialization is critical to the success of the CAA mission. 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 which are based upon the SAM architecture, the Contaminant Analysis Automation group is working toward a standardized and modular approach to laboratory automation. SAMs are integrated systems comprised of Standard Laboratory Modules or SLMs.

The CAA Project is also a highly collaborative effort comprising engineering teams in five DOE National Laboratories. The CAA Team is currently seeking an industrial partner to provide system integration for CAA-developed technology. In addition to this primary industrial collaboration, many SLM manufacturers will be directly contracted or engaged for SLM development via a CRADA involving one of the CAA National Laboratories.

TECHNOLOGY NEEDS

The CAA project consists of the development of SLMs within the DOE Laboratories in collaboration with many SLM manufacturers under CRADAs. Two analysis methods will be commercialized first: the EPA-regulated Methods 3540 and 3550 (the Soxhlet and Sonication extraction of semi-volatile contaminants from soils). The integrated SAMs that will automate these methods are scheduled to be demonstrated late in calendar year 1994. Market assessments, both internal to DOE and within the general laboratory automation market, will aid the CAA team in identifying future SAMs. Evaluation and contracting of SLM manufacturers for these first SAM Systems began in 1993.

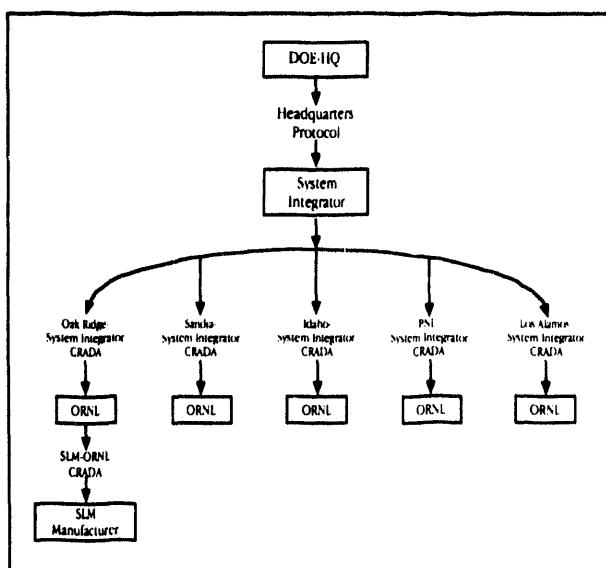


Figure 2.5. Headquarters Protocol and Guidance Document.

ACCOMPLISHMENTS

- An equitable process was structured and executed to select the SAM Systems Integrator.
- A SLM manufacturer workshop was also held to familiarize potential manufacturing firms with the CAA paradigm and existing technology. Over 20 firms expressed interest in further collaboration.
- Several CAA Technology Transfer Council meetings have taken place with the innovative transfer plan resulting.

COLLABORATION/TECHNOLOGY TRANSFER

The CAA Technology Transfer Plan begins with a Headquarters-level Protocol and Guidance document (see Figure 2.5). Imbedded in this document is the detail of CAA Program management, responsibilities, and team interactions. This CAA Protocol will be signed by all of the involved National Laboratories, the

industrial partner, and DOE. Mentioned in this Protocol are two red-lined CRADAs; one to be put in place between each National Laboratory and the industrial partner (with very minimal laboratory contractor customization) and another to be used for contracting SLM manufacturers by the CAA Team Laboratories. Both red-lined CRADAs detail the CAA Program licensing rights and intellectual property flows while referencing, and being bound by, the Headquarters Protocol.

For further information, please contact:

Robert Hollen

CAA Coordinator

Los Alamos National Laboratory

(505) 667-3186

Randy Tremper

Technology Transfer Specialist

Los Alamos National Laboratory

(505) 665-2134

Robotics Mixed Waste Operations

Section 3.0

3.0

ROBOTICS MIXED WASTE OPERATIONS

The Mixed Waste Operations Team (MWO) is one of five technical groups which comprise the Robotics Technology Development Program. It is composed of six DOE laboratories and sites working with industries and universities to develop state-of-the-art technology to store and treat low-level and transuranic mixed wastes. The Team works closely with the Mixed Waste Integrated Program in identifying and prioritizing needs and opportunities to cleanup over 240,000 cubic meters of low-level mixed waste at DOE sites. Actual cleanup is expected to generate approximately 900,000 cubic meters of waste over the next five years. During this time, the waste will need to be monitored during storage, then treated and disposed of in accordance with Federal and state regulations. Robotics is playing an integral part in this cleanup effort with faster, safer, and more cost-effective methods.

Robotics MWO is coordinated through the Savannah River Technology Center, with Clyde Ward as the lead Technical Coordinator and Randy Singer as Alternate Coordinator. Team participants include representatives from the following DOE sites:

Fernald Environmental Management Site (FEMP)
Idaho National Engineering Laboratory (INEL)
Lawrence Livermore National Laboratory (LLNL)
Oak Ridge National Laboratory (ORNL)
Sandia National Laboratories (SNL)
Savannah River Technology Center (SRTC)

Major objectives of MWO are presented in detail in the following chapters and include specific points of contact.

3.1 AUTOMATED WORKCELL MODEL UPDATING

TASK DESCRIPTION

Computer models of the environment are being used for graphical programming, path planning and collision avoidance of robots being developed for mixed waste treatment facilities. This task will demonstrate, test and evaluate systems to update a typical mixed waste workcell model accurately, quickly and easily. A structured light system from Sandia National Laboratories and Mechanical Technologies Inc. (MTI) has been installed in the Telerobot facility at Savannah River Technology Center (SRTC). The Telerobot facility is typical of the environment expected in mixed waste facilities. After initial demonstration of proof-of-principle, the system modeling speed and accuracy will be improved. Automatic entry of the information derived by the structured light system into the computer model with a minimum of geometric shapes while retaining required accuracy will be developed. Operator interaction to quickly and accurately enter repetitive and well known objects, such as 55-gallon drums, will be developed. Competitive systems, i.e., laser camera systems, will be evaluated for this application in the future and compared to structured light for speed, accuracy and ease of entry into the simulation model.

TECHNOLOGY NEEDS

Model-based technology being developed for path planning and collision avoidance will be important in the efficient and safe operation of mixed waste facilities using the Generic Intelligent System Control (GISC). The graphical simulation capabilities of GISC require an

accurate and current model to be useful. Because of the high volume of different containers (drums, bins and boxes) and high volume of different waste items that will be entering, moving through, being treated in and leaving mixed waste treatment facilities, a system to automatically and constantly update the model of the workcell will be required. This system must be accurate, fast and easy to operate.

ACCOMPLISHMENTS

A structured light modeling technology well suited to large environments has already been demonstrated in a waste tank, approximately 80 feet in diameter, at the Fernald Environmental Management Project. This technology has been adapted and enhanced for automated updating of a typical mixed waste workcell. The workcell is approximately 20 feet by 20 feet in area. A metal box, representing a large waste item such as a glovebox, was placed in the workcell but not entered into the model. The structured light system used four identical stations at each corner of the workcell to model the box. Each station has two precise stages with very accurate feedback that act as a pan-and-tilt mechanism. These stages manipulated a camera and laser line generator (laser and lens). One station passed the laser line across the workcell, while a camera on a second station tracked the line. By repeating this with two to four laser/camera pairs, the shape and location of the box was calculated. This information was then automatically entered into the graphical simulation system as a model of the box. The model was accurate to a plus or minus 1 inch in this application.

COLLABORATION/TECHNOLOGY TRANSFER

Sandia National Laboratories has a CRADA with Mechanical Technologies, Inc. on a structured light modeling system. MTI, with assistance from SNL, has provided a structured light system to the Savannah River Technology Center that demonstrated automated updating of a typical mixed waste workcell model. As improvements in accuracy and speed are

developed, they will be available for technology transfer to industry.



Figure 3.1a. Waste characterization conveyor passing through characterization stations.

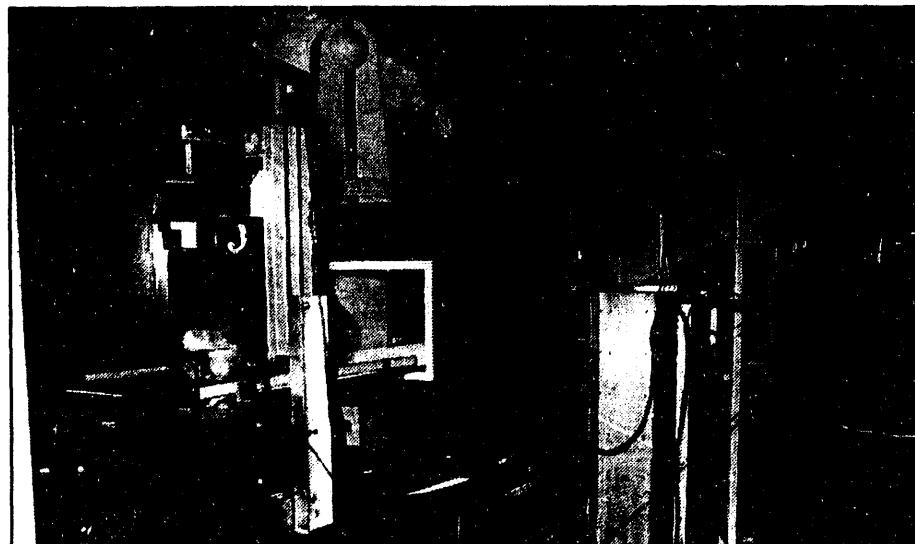


Figure 3.1b. Trays of waste automatically sorted

For further information, please contact:

Clyde Ward

Mixed Waste Operations Coordinator
Savannah River Technology Center
(803) 725-5891

Ray Harrigan, PhD

CC&AT Coordinator
Sandia National Laboratories
(505) 844-3004

Colin Selleck

Structured Lighting Engineer
Sandia National Laboratories
(505) 844-9662

William Hamel, PhD

D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

Reud Kress

Structured Lighting Engineer
Oak Ridge National Laboratory
(615) 574-2468

William Mallet

Structured Lighting Engineer
Savannah River Technology Center
(803) 725-1481

3.2 WASTE ITEM CHARACTERIZATION AND SORTING

TASK DESCRIPTION

This task will develop a system for remote characterization of mixed waste material while still in a drum or other container and after removal from the container, as well as sorting of the objects. LLNL has demonstrated characterization of whole drum contents using active/passive computed tomography. However, this work will be suspended temporarily to concentrate on the more immediate need of characterization of individual items. Autonomous radiographic and material characterization of waste items will continue the development of characterization of single items placed in trays (singulation) and sorted as the trays travel down a conveyor. The sorting criteria will be based on information from the Mixed Waste Integrated Program (MWIP) and the Mixed Waste Treatment Project (MWTP). Technology to accomplish this priority sorting will be developed. This task will leverage previous work accomplished at LLNL.

TECHNOLOGY NEEDS

Mixed waste treatment facilities will have to characterize most or all of the material entering the facility in order to determine its acceptability for the different treatment processes and sort the material for treatment. Characterization of the contents of the entire container (drum, box or bin) may be necessary to determine if containers can enter the facility, to campaign material types and for omnivorous treatment, i.e., the plasma hearth process. Characterization and sorting of material removed from containers will be required for treatment processes that require specific ma-

terial, i.e., decontamination, and the higher accuracy and resolution that individual item characterization can provide. This characterization and sorting of hundreds of thousands of cubic meters of mixed waste in the DOE complex must be done efficiently and accurately. Remote characterization and sorting will also reduce exposure, risk of injury and the generation of secondary waste from personal protective clothing.

ACCOMPLISHMENTS

An active/passive neutron interrogation and computed tomography system is being developed for drums of mixed waste. This system can determine the types and approximate quantities of different materials, including radioactive material, inside the drum and show the location of the material in a 3-D representation of the drum and its contents. The different types of material are color-coded in the 3-D display to provide an easily understood representation of the data. This equipment is at LLNL. Depending on the resolution and accuracy desired, this operation presently can take hours. However, techniques and equipment modifications to speed the process without a reduction in resolution or accuracy are being investigated. Initial tests of this same technology to characterize typical mixed waste items have had encouraging results. Cross-sections and 3-D models of items have been generated that indicate the location of different types of materials throughout the item.

A characterization system for dry heterogeneous material has been demonstrated by LLNL. Typical mixed waste items were char-

acterized without removing them from the single or multiple plastic bags that are typical for this material. An individual waste item was placed into a tray, and the tray was conveyed through a series of sensors to determine its properties. The sensors determined if there was significant metal in the item, and what type of metal. Another sensor determined if there was significant radioactive material in the item, and what radioisotopes were present. Yet, another sensor determined the approximate size of the item, and with the weight previously determined by the force sensor during singulation, average density was determined. Additional sensors could be added to this system to increase its characterization capabilities.

The information received from the characterization system was used to sort the trays for different treatment options. The trays were automatically diverted from the main conveyor onto side conveyors that would be sent to different treatment processes in an actual facility. In some cases the material could be conveyed into another cell and processed in gloveboxes. Highly contaminated items or specific types of contamination on items could remain inside the plastic bags and only be opened in a specific glovebox to segregate contamination and aid in contamination control.

COLLABORATION/TECHNOLOGY TRANSFER

This technology developed by LLNL, will be available for transfer to industry when it is mature.

For further information, please contact:

Erna Grasz

LLNL Site Representative
Lawrence Livermore National Laboratory
(510) 423-6556

Clyde Ward

Mixed Waste Operations Coordinator
Savannah River Technology Center
(803) 725-5891

3.3 WASTE CONTAINER OPENING AND TRANSPORTATION

TASK DESCRIPTION

This project is developing technology for remote opening of drums, bins and boxes of waste and remote transport of drums in mixed waste facilities (see Figures 3.3a and 3.3b). Eventually, transporting these containers between facilities will be addressed.

The concept for remote drum opening includes a vertical-axis, rotating chuck for 30-, 55- and 83-gallon drums. There are two opposing towers on either side of the chuck. Idler wheels to support the drum are engaged from one tower. Tools are deployed from the opposite tower as the drum is rotated. After the drum is cut and the top is removed, tools that can be quite different from those used to cut the metal drum, are deployed to cut the plastic liner.

The concept for remote box and bin opening is the deployment of special tools by a gantry robot to cut the top of the box and bin. The gantry robot will allow the remote opening of many different size boxes and bins. High-pressure liquid nitrogen cutting will be tested and evaluated as a tool for opening both metal bins and wood boxes.

The existing material transport control systems in place at the Fernald Environmental Management Project (FEMP), which are thought to be typical of systems at other DOE sites, will be investigated. It is anticipated that computer aided dispatch and monitoring of materials handling vehicles at FEMP and other sites will provide optimized transport and

documentation. An investigation of state-of-the-art material transport to and from facilities will also be conducted. The results and conclusions of this investigation will be used to guide technology development in this area.

TECHNOLOGY NEEDS

Tens of thousands of waste drums, bins and boxes will have to be transported inside waste treatment facilities. Manual handling would be a safety risk, especially with the large number of containers that will be processed over the life of a facility. The large bins and boxes would likely be transported by overhead crane. Another task in the Mixed Waste Operations Robotics Program, Swing-Free Crane Control, remedies this problem. There are many options for remote drum transport. However, if a gantry robot with a suitable work envelope and load capacity is available, a drum lifting end effector can quickly and reliably move drums in a precise path and location into top-loading machines. This concept does not require the floor space, large volume of components that will eventually become waste, and the maintenance of a large conveyor system. Also, a gantry robot is much more flexible. As needs change within a facility, material flow and storage locations can easily be changed with a drum lifting end effector on a gantry robot. Stacking drums to minimize floor space is feasible with this concept.

Waste containers must be opened in waste treatment facilities to remove their contents. Many of the drums and bins as well as their fasteners will be corroded and deteriorated, making lid removal difficult. Manual opening could risk injury from exertion, power tools and sharp edges. Remote container opening would reduce risk of injury, reduce secondary waste from personal protective clothing and increase throughput. For metal drums and metal drums with plastic liners, the drum may be chucked and rotated while special tools are used to cut the drum and the liner. Many different sizes of boxes and bins must be accommodated. For wood boxes and metal bins, a process that does not ignite the wood container or combustible material inside is required. This process should not be compromised by contact with material inside the containers. Saws that cut wood boxes can be ruined by contact with nails in the box and metal objects inside the box. Thermal cutting,

such as plasma arc cutting, can cut open a metal bin, but would ignite the combustible material inside the bin.

As the site cleanup effort increases, the volume of waste containers requiring transport within the site will increase. A safe and efficient material handling system is required for this container transport.

ACCOMPLISHMENTS

A drum lifter end effector has been designed, built, tested and is being evaluated. It has been tested with a 55 gallon drum that weighed over a thousand pounds and performed well even with deformed drums. The drum lifter includes an Applied Robotics tool changer that allows it to be picked up, operated and returned by a suitably equipped and compatible gantry robot. It has sensors that measure relative force and displacement of the lifting straps. These sensors are monitored and used for control during operation. It has been demonstrated picking up and loading a drum into a remotely operated drum opener and removing parts of the drum and liner after cutting. The drum lifter is currently being tested and evaluated.

The drum and liner opening system has demonstrated remote opening of a 55-gallon drum and 0.090 inch thick plastic liner. Tools and supports are deployed from opposing masts and can be remotely manipulated up and down on the mast and in and out. A sharp-edged wheel has been used to cut the metal drum. Both a power saw and a parting tool have been used to cut the plastic liner. Many sensors are used on the equipment to remotely monitor and control operation of the system. Many different types of tools and different tech-

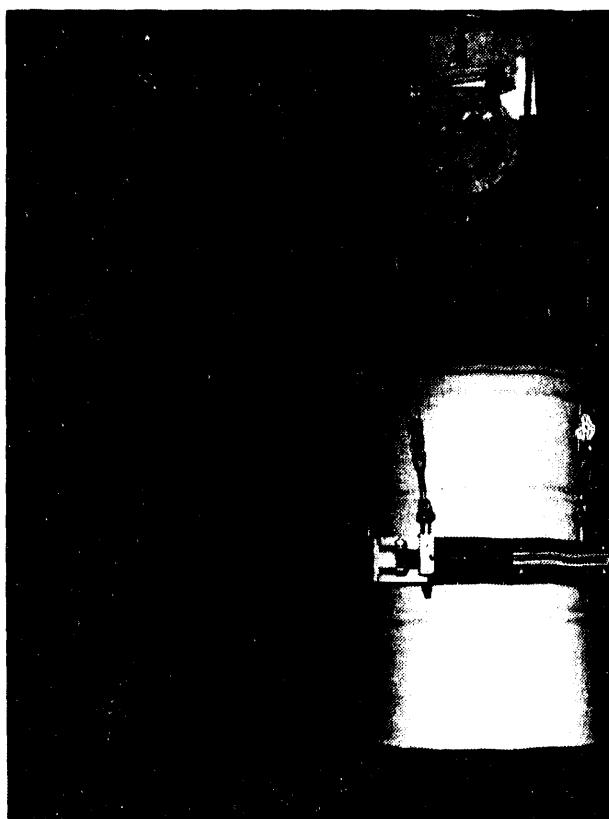


Figure 3.3a. Drum lifter end effector.

niques will be tested on this system as the testing and evaluation continue.

design of actual equipment for the WCF and other mixed waste facilities.

COLLABORATION/TECHNOLOGY TRANSFER

The tool changer for the drum lifter is the first electrically actuated tool changer developed by Applied Robotics. The drum and liner opening equipment designed and installed at the SRTC is similar in concept to the proposed Waste Characterization Facility (WCF) at INEL. The concept drawings of the drum and liner opening equipment for the WCF were provided by Merrick & Company and many of these concepts were included in the SRTC final design. Initial testing of the SRTC equipment identified tools and techniques that will open drums and liners. Other types of tools and techniques will be tested to optimize the process. The results will be available to Merrick & Company and other companies to aid in the

For further information, please contact:

Clyde Ward

Mixed Waste Operations Coordinator
Savannah River Technology Center
(803) 725-5891

Jeffrey Brault

Drum Opening Team Leader
Westinghouse Savannah River Company
(803) 725-1713

Bruce Wilding

INEL Site Representative
Idaho National Engineering Laboratory
(208) 526-8160



Figure 3.3b. Drum and liner opening system.

TASK DESCRIPTION

This task will develop remote removal and placement of individual waste items (singulation) from their initial containers. (see Figure 3.4). These singulated items will be typical of solid, dry, heterogeneous, mixed waste. This task will develop autonomous capabilities including automated modeling technology, autonomous grasping, collision avoidance and force control to provide autonomous singulation for a majority of waste items from drums, bins and boxes. Initial work will use manipulators with a capacity of 40 pounds or more to include most waste items in drums, and then expand to manipulators with a capacity of 200 pounds or more to include all of the items in drums and many of the items expected in bins and boxes. The manipulators must be appropriate for operation, maintenance and repair in mixed waste treatment facilities. Autonomous operation will provide the highest productivity, but due to the variety

and uncertainty of waste items, teleoperation will be required for some of the waste items. Therefore, this task will also enhance teleoperation capabilities with remote viewing, force control and other techniques to increase productivity with equipment suitable for mixed waste facilities.

TECHNOLOGY NEEDS

Throughout many years of operation in mixed waste facilities, high volumes of solid, dry, heterogeneous, mixed waste must be removed from drums, boxes and bins and individually separated (singulation) for characterization and treatment. Opening the containers can produce sharp and jagged edges and the objects, i.e., glass vials and motors, may have sharp edges difficult to remove. Manual removal of these items would expose personnel to radiation and hazardous material and create safety risks. Any contact to personnel in this environment is potentially hazardous. An extended reach would be required for heavy items at the bottom of drums. Remote singulation is needed to reduce personnel risk and exposure, to increase throughput and reduce secondary waste generated from manual operation (personal

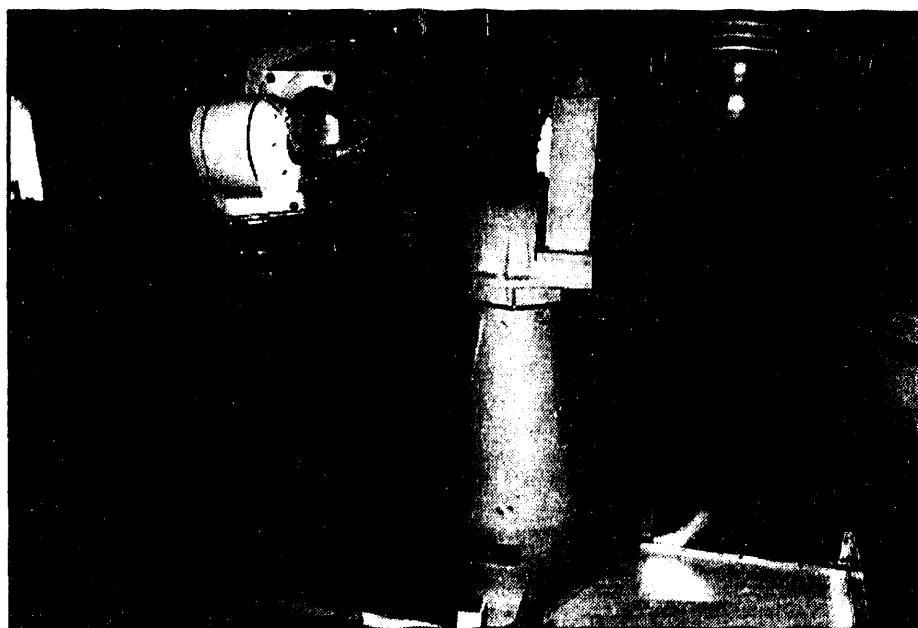


Figure 3.4. Robotic waste removal and characterization

protective equipment).

ACCOMPLISHMENTS

Teleoperated singulation has been demonstrated with a PUMA robot with a payload of approximately 40 pounds. A JR3 force sensor was attached to the wrist to measure forces and moments, and a Robohand tool changer allowed the use of many different end effectors. To provide efficient use of this industrial robot in a teleoperated mode, a Generic Intelligent System Control (GISC) compatible software module called SMART (Sequential Modular Architecture for Robotics and Teleoperation) was used. SMART allows the use of many different master input devices; however, a Dimension 6 force ball by CIS was used to manipulate the PUMA during the demonstration. This device was used by the operator to remotely control the PUMA robot, using external cameras and cameras mounted on the PUMA to find the objects. SMART also used the force sensor to prevent excessive forces and moments from being developed during singulation that could damage the robot, waste items, or surrounding equipment. The force sensor was also used to determine the weight of the waste item. Waste items from a drum and a pile were deposited in trays at the inlet to a waste item characterization system.

Staubli and is available for technology transfer. Future work will develop this technology for higher payload robots, such as the PAR systems gantry robot, and for ultimate transfer to the field. Some of the structured light modeling technology has already been transferred by SNL and ORNL to Mechanical Technologies, Inc. through CRADAs and additional modeling technology will be available in the future.

For further information, please contact:

Erna Grasz

Site Representative

Lawrence Livermore National Laboratory
(510) 423-6556

Ray Harrigan, PhD

CC&AT Coordinator

Sandia National Laboratories
(505) 844-3004

William Hamel, PhD

D&D Coordinator

Oak Ridge National Laboratory
(615) 574-5691

Clyde Ward

Mixed Waste Operations Coordinator
Savannah River Technology Center
(803) 725-5891

COLLABORATION/TECHNOLOGY TRANSFER

Sandia National Laboratories, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, and Savannah River Technology Center are collaborating on this task. Initial singulation was accomplished on a commercially available PUMA robot by

3.5 STORED WASTE AUTONOMOUS MOBILE INSPECTOR

TASK DESCRIPTION

This project will develop a Stored Waste Autonomous Mobile Inspector (SWAMI) to demonstrate the potential for drum inspection and floor survey in waste drum warehouses. This system will show the feasibility to augment the current manual inspection and provide documentation, inventory and radiation data that is not currently available from manual inspection. The robot is based on the HelpMate mobile robot by Transitions Research Corporation. SWAMI will be able to navigate autonomously through simulated drum storage warehouses and capture a video image of each drum, read the bar-coded number of the drum and store the image, drum number, time, date and physical location in an on-board computer system. This information will be downloaded

into an off-board computer database at the end of each run. The images and inventory information from previous inspections will be stored in this database for comparison, documentation and trending analysis. The inventory information will also be transferred to the site database so that the inventory will be updated every time an inspection is completed. SWAMI will also perform a radiation survey of the floor in the aisles during each inspection. SWAMI will stop and notify appropriate personnel if high contamination is encountered during the inspection. The radiation data will be downloaded into the off-board computer after each inspection and radiation maps of both alpha and beta/gamma levels in the aisles will be generated. These radiation maps will also be stored in the computer for documentation and trending analysis. The radiation survey technology is based on the Semi-Intelligent Mobile Observing Navigator (SIMON) developed previously on a Cybermotion mobile robot.

SWAMI will use the GISC for supervisory control of all subsystems. GISC is the computer architecture and software used throughout the DOE Robotics Technology Development Program to minimize costs and development time and maximize software reuse and compatibility.

A SWAMI II will be developed specifically for drums of waste stored in facilities at the FEMP. SWAMI II will be able to autonomously drive backward to operate in the aisles at FEMP, many of which are dead-ended. This system will be tested at FEMP to meet objectives mutually agreed upon with the FEMP regional EPA.

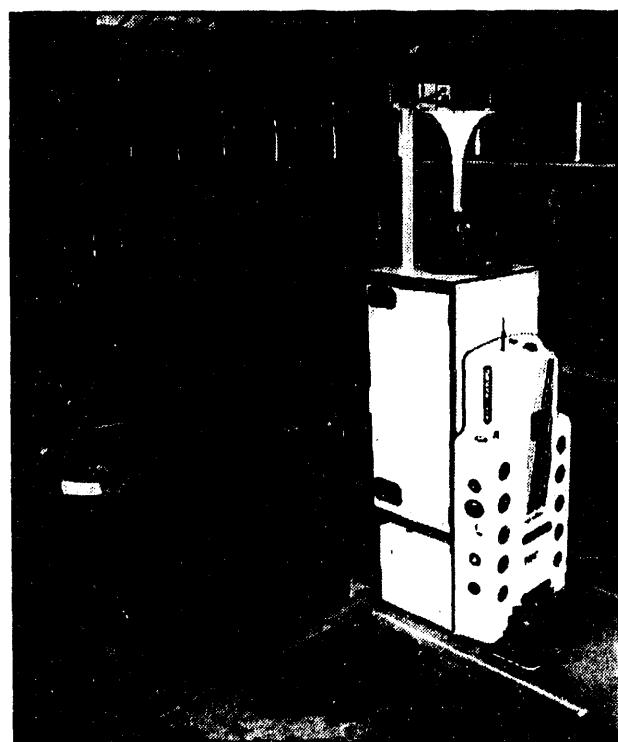


Figure 3.5. Stored Waste Autonomous Mobile Inspector.

TECHNOLOGY NEEDS

There are tens of thousands of drums of low-level radioactive, hazardous and mixed waste stored at each of several major DOE sites. EPA regulations require weekly inspection of these drums. This is currently done manually and is a monotonous task. Manual inspection provides very limited documentation on the condition of these drums and inventories are updated on an infrequent basis. Robotic and vision systems can augment and improve the efficiency, documentation and accuracy of drum inspections and inventory.

If a spill of radioactive material occurs, the inspectors can spread the contamination throughout the facility before detecting contamination on their shoes when they monitor the warehouse exit. It has been shown at Savannah River Technology Center that a mobile robot can detect floor contamination much more reliably and accurately than manual surveys conducted over a long period of time.

ACCOMPLISHMENTS

SWAMI has been demonstrated in a drum storage warehouse mockup with typical 55-gallon drums on pallets stacked three levels high. SWAMI navigated through the open-ended aisles carrying a radiation detector and six sets of bar code readers, cameras and strobe lights to gather information. The drum images were compressed and stored on-board the robot during the inspection. Radiation data and corresponding positions were also stored on-board. At the end of the inspection, all data was downloaded to an off-board computer while the robot was being recharged. The uncompressed drum images along with the drum numbers, dates, and positions (warehouse coordinates of the robot) were displayed on the off-board computer after inspection.

Radiation maps of data taken during an inspection have been displayed. SWAMI has also located a radiation source placed in the aisle and provided immediate notification over the radio link as well as stopping and flashing on-board lights.

COLLABORATION/TECHNOLOGY TRANSFER

Martin Marietta Astronautics is developing a vision analysis system through a PRDA. This system will analyze the drum images and detect rust spots and streaks (potential leaks). These suspect images would be presented to the operator for disposition. The operator can compare these images to previous images of the same drums taken by SWAMI to determine if these rust spots and streaks were there previously and if they are increasing in size or intensity. This technology will be added to SWAMI and SWAMI II to increase the ability of the operator to locate drums requiring action.

The Savannah River Technology Center has been working closely with Transitions Research Corporation (TRC) to develop their mobile robot for this application. TRC has limited the HelpMate to hospital applications until this time. TRC modified the HelpMate for the SWAMI application with special sensors to navigate between pallets and calibrate position, and a unit to hold the radiation sensors. The technology developed at SRTC includes off-board control and display, on-board control, radio ethernet communications, image recording, image compression, image storage, bar code reading, radiation survey and radiation data display. This technology will be available to TRC and other mobile robot companies, such as Cybermotion. The radiation mapping software is being copyrighted to fa-

cilitate the transfer of this software to the mobile robot industry.

The on-board supervisory system was developed by the University of South Carolina. It is the first commercial mobile robot to use the Generic Intelligent System Control for operation.

For further information, please contact:

Kurt Peterson

SWAMI Team Leader

Westinghouse Savannah River Company

(803) 725-1180

Clyde Ward

Mixed Waste Operations Coordinator

Savannah River Technology Center

(803) 725-5891

Brack Hazen

Fernald SWAMI Coordinator

Fernald Environmental Restoration Manage-

ment Company

(513) 648-6554

3.6

SWING-FREE CRANE CONTROL

TASK DESCRIPTION

Swing-free crane control allows a load suspended from a cable on a gantry crane to be moved without inducing any undesired swing. The basic swing-free technology has been patented by Sandia National Laboratories (SNL). The initial technology required prior knowledge of the period of swing, which is dependent on the pendulum length, and prior knowledge of the desired path of the load. As part of this task, SNL and ORNL developed operator-in-the-loop swing-free control. This allows the operator to control the movement of the load in real time with a standard crane pendant or other input device, so the path does not have to be preprogrammed. As part of this task, SNL also has developed sensor-based, swing-free crane control where a sensor at the top of the cable measures cable displacement, so that swing-free control can be automatically implemented regardless of the period of swing. All of this technology has been demonstrated on a gantry robot at SNL. The main objective of this task is to implement all of this technology on a standard, AC motor-driven gantry crane, and transfer it to industry, so that it is available for use in mixed waste facilities or in any facility that incorporates a gantry crane. Implementation of this technology on a gantry crane is being developed, demonstrated, tested and evaluated by Oak Ridge National Laboratory.

TECHNOLOGY NEEDS

Drums, and particularly, large, heavy containers, such as boxes and bins would likely be transported by overhead crane in mixed waste facilities. Operation of an overhead crane, especially by inexperienced operators, can cause severe swinging of the load which is dangerous to the operator and can damage the load or the facility. Swinging can also significantly increase the time required to move loads, particularly the time required to manually dampen out the swing before a load can be lowered. These problems are increased in a remote facility due to the distance of the operator from the load and restricted vision. A system to automatically provide swing-free transport of loads with a gantry crane, regardless of weight, height or path of the load would increase throughput and safety in mixed waste facilities.

ACCOMPLISHMENTS

The basic swing-free technology has been patented by Sandia National Laboratories and demonstrated on a gantry robot. This technology has been transferred to Oak Ridge National Laboratory where it and new algorithms have been demonstrated on a gantry crane. The crane is a standard, 30 ton, AC motor-driven crane, using new vector drives recently available from industry. Swing-free operation of this crane has been shown to reduce swing by an order of magnitude.

COLLABORATION/TECHNOLOGY TRANSFER

Sandia National Laboratories and Oak Ridge National Laboratory are seeking gantry crane manufacturing companies interested in implementing this technology on new cranes and companies interested in retrofitting existing cranes with this technology. It is anticipated the demonstration of operator-in-the-loop, sensor-based, swing-free crane control on a standard gantry crane will stimulate interest in transfer of this valuable technology.



For further information, please contact:

Ray Harrigan, PhD

CC&AT Coordinator

Sandia National Laboratories

(505) 844-3004



Clyde Ward

Mixed Waste Operations Coordinator

Savannah River Technology Center

(803) 725-5891

William Hamel, PhD

D&D Coordinator

Oak Ridge National Laboratory

(615) 574-5691



TASK DESCRIPTION

This task will develop and demonstrate remote and autonomous robotic systems for mixed waste processing operations. The immediate goal is to identify and develop an automated system for handling and treating high priority non-combustible mixed waste debris to meet Resource Conservation and Recovery Act disposal guidelines. This includes autonomous modeling and grasping of waste objects, and autonomous surface modeling and surface following technology for the selected surface treatment tool.

TECHNOLOGY NEEDS

Many different processes will be required in mixed waste treatment facilities to treat different mixed waste streams and place them into their proper final waste forms. These processes must be reliable, efficient and safe. Remote, autonomous operation will provide the technology required to achieve this. For example, manual manipulation of lead bricks for decontamination would be monotonous, risk injury from extended reach and continuous lifting of heavy loads, or from manipulation before a frozen CO₂ pellet blast nozzle. Robotic manipulation would provide uniform manipulation during decontamination for the highest efficiency and be able to reblast only those areas determined by a radiation survey to be still contaminated.

ACCOMPLISHMENTS

A glovebox gantry robot is in operation at LLNL. It is capable of remote operation of many treatment processes for mixed waste operations. The robot is enclosed in a glovebox so that gloveports may be used for maintenance and address unusual situations. The robot is modular so that components may be replaced with the use of gloveports. It is electrically actuated and operates in different types of glovebox atmospheres (air, nitrogen, argon, partial vacuum, etc.). It is capable of teleoperation as well as programmed operation, and has a lifting capacity of 80 pounds. A parallel jaw gripper is used to perform operations and manipulate objects in the glovebox. The robot has been used to pick up and transport a simulated lead brick, manipulate it in front of a frozen CO₂ blasting nozzle, manipulate it in front of a radiation detector and palletize it for removal from the glovebox in demonstrations at LLNL and Savannah River Technology Center (SRTC).

An autonomous grasping system using algorithms developed at LLNL and a stereo vision system has been demonstrated. A structured light system developed at ORNL has also been demonstrated. This system is capable of modeling waste items much faster and with higher accuracy than the stereo vision system. Work to integrate the structured lighting system and autonomous grasping is underway.

A frozen CO₂ blasting system to simulate decontamination of a lead bricks has been demonstrated. It propelled small frozen CO₂ pellets with air from a nozzle. This system has previously been demonstrated to be effective

in decontamination of radioactively contaminated surfaces. For this application, the brick was manipulated in front of a stationary blast nozzle by the glovebox robot. This eliminated the hose management problem (snagging, wear and recontamination) of draping hoses during manipulation. Information on the location of remaining contamination could be used to reblast only those specific areas. Use of robotics for this operation assures complete and uniform blasting of each brick and complete and uniform survey of each brick. This technology could also be applied to different treatment processes where accurate following of the surface of a waste item is required.

COLLABORATION/TECHNOLOGY TRANSFER

LLNL, ORNL, SNL, and SRTC have collaborated on this task. LLNL has collaborated with International Business Machines to develop an electric gantry robot suitable for operation in a glovebox, and is also collaborating with Cimetrix to enhance their Robline robot control system to be compatible with the GISC. LLNL and SRTC have worked with Alpheus to provide a stationary frozen CO₂ blast system for decontamination of lead bricks. ORNL has a CRADA with Mechanical Technolo-

gies, Inc. on a structured lighting modeling system suitable for modeling waste items. All of this technology will be available for transfer to industry.

For further information, please contact:

Erna Grasz

Site Representative
Lawrence Livermore National Laboratory
(510) 423-6556

Ray Harrigan, PhD

CC&AT Coordinator
Sandia National Laboratories
(505) 844-3004

Clyde Ward

Mixed Waste Operations Coordinator
Savannah River Technology Center
(803) 725-5891

William Hamel, PhD

D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

Robotics Decontamination and Dismantlement

Section 4.0

4.0

ROBOTICS DECONTAMINATION AND DISMANTLEMENT

There is 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, facility deactivation, followed by a period of surveillance and maintenance (S&M) pose many of the problems that will need to be addressed in ultimate D&D activities. Deactivation and S&M activities place emphasis on characterization, data capture, and selective D&D in order to define and minimize the risk and cost associated with possible long-term S&M activities required prior to final D&D. The overall emphasis of the D&D application area of the DOE EM, OTD, RTDP is to focus on systems and capabilities that can be used in facility deactivation and on-going S&M activities with extended application to final facility D&D tasks.

4.1 SURVEILLANCE AND MAINTENANCE RISK AND COST REDUCTION EVALUATION METHODOLOGIES

TASK DESCRIPTION

The Surveillance and Maintenance (S&M) Risk and Cost Reduction Evaluation Methodologies activity provides for the development of analysis methodologies for evaluation of risk and cost/benefit tradeoffs associated with robotics systems in reducing facility S&M costs. Applications for robotic systems during both facility deactivation and continuing S&M will be considered. Assessment of methodologies will be performed and include collection of sufficient information regarding deactivation and ongoing S&M tasks to define pertinent parameters for the development of a meaningful evaluation methodology. From the assessment of methodologies, a final strategy/approach will be selected and will establish the methodology to be used for on-going S&M evaluations. Evaluations on candidate facilities will be performed to test and refine the methodology.

TECHNOLOGY NEEDS

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

ACCOMPLISHMENTS

This activity is being initiated in FY94. Future accomplishments are expected to include:

- Assessment of methodologies will be performed in the first half of FY94 and a final strategy/approach will be selected that will establish the methodology to be used for on-going S&M evaluations.
- Evaluations will be performed on candidate facilities to test and refine the methodology during FY94.
- A refinement/update process based upon applications experience will be initiated in FY95.

COLLABORATION/TECHNOLOGY TRANSFER

This technology is being jointly developed by Oak Ridge National Laboratory and Sandia National Laboratories.

For further information, please contact:

William Hamel, PhD
D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

MAPPING, CHARACTERIZATION, AND INSPECTION SYSTEM

TASK DESCRIPTION

The Mapping, Characterization, and Inspection System activity provides for development and demonstration of a multi-purpose mobile robotic system for facility mapping, contaminant characterization, and inspection functions associated with facility surveillance and maintenance (see Figure 4.2). Additionally, development will begin on hierarchical data acquisition, data management, and data display capabilities for three-dimensional facility mapping, contaminant mapping and record keeping, and contamination/configuration tracking. The mobile robotic system will initially perform floor characterization using radiation sensors to generate contaminant information to be used as the initial data for the facility mapping system. The facility mapping system will provide a capability to capture facility geometry data upon which

contaminant data may be mapped. A facility mapping capability allows capture of characterization data and identification of candidate areas for selective D&D, which can be evaluated relative to minimizing the on-going S&M risks and cost. As activities occur, the mapping system can be updated to reflect current conditions and maintain facility configuration information. The mapping system will maintain this data for use in eventual D&D activity planning, control, and monitoring. This task will interact and incorporate the results from the DOE EM, Office of Technology Development funded Program Research and Development Announcement (PRDA) contracts for mapping capability with Mechanical Technology, Inc., and Coleman Research.

TECHNOLOGY NEEDS

Facility deactivation and S&M activities place emphasis on characterization and data capture in order to define the condition of the facility and minimize risk and cost associated with possible long-term S&M activities required prior to final D&D. The physical and contaminant characterization of a facility in question can be performed manually or with remote or robotic system assistance. The data generated from these activities needs to be captured in a form that is readily usable for visualization of the

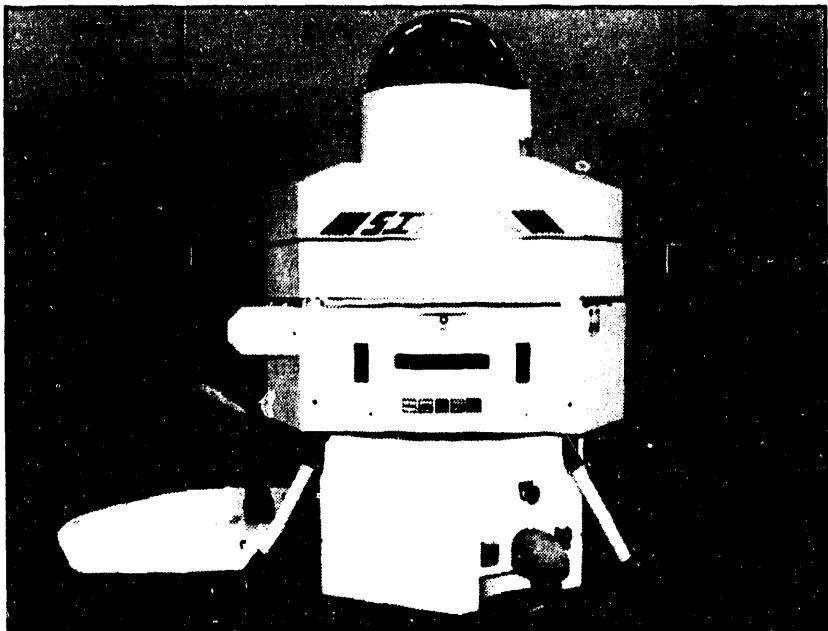


Figure 4.2. Mobile Floor Characterization Robot

facility, equipment, and possible contaminants, as well as input for control purposes for remote or robotic systems that might be used during deactivation, S&M, or final D&D. Such a system can also provide a long-term record of facility configuration and condition as deactivation, S&M or D&D activities take place.

A system to perform floor characterization has been identified for development under this activity since there are hundreds of acres of floor space in DOE facilities that require characterization and ultimate decontamination. These 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. Floor characterization using mobile robotic systems is faster, produces reliable, repeatable data, and reduces waste and personnel exposure.

ACCOMPLISHMENTS

This activity is being initiated in FY94. Future accomplishments are expected to include:

- Requirements and conceptual design developed for facility mapping system in the first half of FY94.
- Capabilities developed by industry (primarily under DOE PRDA contracts) will be evaluated for completeness and functionality. Additional functions, as required, will be prototyped to provide an initial system capability for demonstration in the fourth quarter of FY94.
- In FY95, data from the facility mapping system will be integrated into system control and simulation capabilities using the interfaces defined in FY94.

- As an initial implementation of the data gathering characterization system, specifications for a floor characterization system based on previous work at Savannah River Technology Center and on requirements determined for use of the system in the Oak Ridge K-25 Site process buildings will be established.
- An industry procurement for the floor characterization system is planned in FY94 with system integration and testing of the floor characterization system targeted for the fourth quarter of FY94 for radiological contamination sensing only.
- In FY95, additional sensors and increased automation capabilities will be added to the floor characterization system.

COLLABORATION/TECHNOLOGY TRANSFER

This technology is being jointly developed by Oak Ridge National Laboratory, Savannah River Technology Center, and Sandia National Laboratories. It will include industry interactions with Mechanical Technology, Inc. and Coleman Research.

For further information, please contact:

William Hamel, PhD
D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

4.3

SELECTIVE EQUIPMENT REMOVAL SYSTEM

TASK DESCRIPTION

The Selective Equipment Removal System (SERS) activity will demonstrate and evaluate a mobile telerobotic system suitable for performing selective D&D functions applicable to pre-S&M facility preparations. The SERS will use a reconfigurable dual-arm manipulation module to demonstrate inspection, decontamination, and equipment removal operations. The dual-arm manipulation module will be deployed from an overhead transporter for initial SERS demonstrations in FY94 (see Figures 4.3a and 4.3b). Vehicle deployment evaluations will be performed in FY94 through interaction with the DOE EM, Office of Technology Development funded Program Research and Development Announcement (PRDA) contract at Carnegie Mellon University (CMU) for the development of a mobile

and analysis capabilities, and a tooling compatibility study. Interfaces to a facility mapping capability will be established to allow data exchange for graphics and control functions.

TECHNOLOGY NEEDS

Hazards associated with contaminated hot cells, canyons, glove boxes, and reactor facilities at DOE sites include radiation, radiological contamination of equipment to be removed, and hazardous chemicals associated with the processes performed at the facilities. Because of these hazards, deactivation, S&M, and ultimate D&D will 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 the capability 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

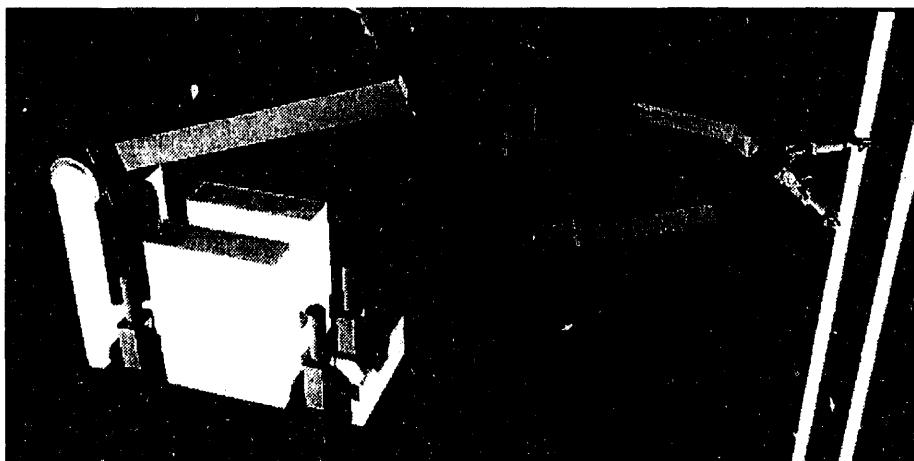


Figure 4.3a. Mobile Dismantlement Work Module.

work system. SERS deployment via a vehicle will be developed in FY95 using the Phase II CMU PRDA system. SERS tasks will include development of operator control console capabilities, development of scene generation

risk and cost associated with potentially long-term S&M activities and final D&D. For pre-S&M facility preparations, or ongoing S&M activities, a remote system capable of being deployed for selective D&D can eliminate high risk or high S&M cost contaminants or equipment.

ACCOMPLISHMENTS

This activity is being initiated in FY94. Future accomplishments are expected to include:

- The system requirements and a conceptual design for the SERS will be developed during the first half of FY94.
- Major SERS subsystem integration will be completed by the end of FY94. Major sub-

systems include a dual-arm manipulation module, 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 will be demonstrated in the fourth quarter of FY94 at Oak Ridge National Laboratory.

- In FY95, vehicle deployment and demonstration of SERS will be completed via integration with the vehicle system being developed under DOE PRDA contract at CMU. Human-machine interfaces and automation enhancements will be developed to support vehicle deployment. Cost effectiveness of telerobotic equipment inspection, decontamination, and removal will be evaluated.
- Expansion and evaluation of automation features will continue in FY96 to extend the range of work tasks to be addressed.

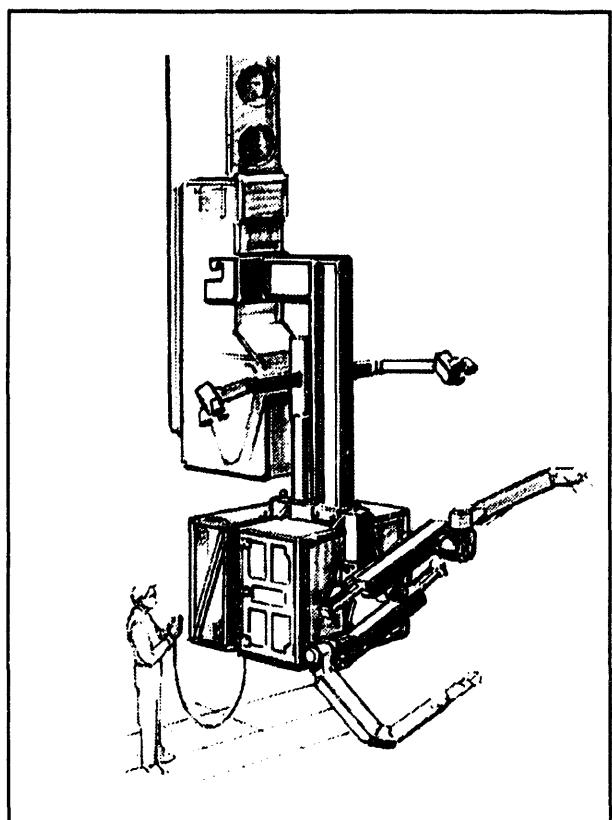


Figure 4.3b. Overhead Dismantlement Work Module.

COLLABORATION/TECHNOLOGY TRANSFER

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

For further information, please contact:

William Hamel, PhD
D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

4.4

SMALL PIPE CHARACTERIZATION SYSTEM

TASK DESCRIPTION

The Small Pipe Characterization System activity provides for the design, procurement, fabrication, integration, and demonstration of a system for characterizing contaminants in pipes with internal diameters between one and three inches. Identification and mapping of contaminants in piping is a major concern during facility deactivation. An understanding of the contaminants and extent of contamination will be primary drivers for decisions regarding piping decontamination and/or dismantlement; all of which affect initial deactivation cost; ongoing S&M risk and cost; and eventual D&D strategy and cost.

TECHNOLOGY NEEDS

Throughout the DOE Complex, there are numerous facilities identified for D&D with piping that has been placed on the contaminated list because of the internal contamination risk. Much of this piping is inaccessible since it is buried in concrete or it runs through hot cells. Currently, there are no robotic/remote systems capable of characterizing pipe in the one to three-inch inside diameter range. Characterization of this piping is essential before, during, and after D&D activities. By identifying those sections of piping not contaminated can greatly reduce the amount of material sent to waste handling facilities or the amount of waste generated performing unneeded decontamination.

ACCOMPLISHMENTS

This activity is being initiated in FY94. Future accomplishments will include:

- Functional requirements and conceptual design developed to define expected performance through valves, bends, and intersections, as well as defining insertion and retrieval processes and travel distances.
- A detailed design will be developed and a prototype system built that will operate in the larger end of the target pipe diameter range.
- A demonstration of operation in piping with internal diameter of three inches is expected by the end of FY94.
- A demonstration of operation in piping of internal diameter as low as one inch is targeted for the end of FY95.

COLLABORATION/TECHNOLOGY TRANSFER

This technology is being developed by the Idaho National Engineering Laboratory. Industrial involvement to promote ultimate commercial availability of the system will be emphasized.

**For further information, please
contact:**

William Hamel, PhD
D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

Mark D. McKay
Technical Lead
Idaho National Engineering Laboratory
(208) 526-5211

[REDACTED]

4.5 INTERNAL DUCT CHARACTERIZATION SYSTEM

TASK DESCRIPTION

The Internal Duct Characterization System activity will demonstrate a remotely operated system for characterizing selected chemical and radiological contaminants which are internally deposited in typical ventilation duct work (see Figure 4.5). The system will include contaminant sampling and hot spot decontamination capabilities. The identification and mapping of contaminants in duct work is a major concern during facility deactivation. An understanding of the contaminants and extent of contamination will be primary drivers for duct work decontamination and/or dismantlement - all of which affect initial deactivation cost, on-going S&M risk and cost, and eventual D&D strategy and cost.

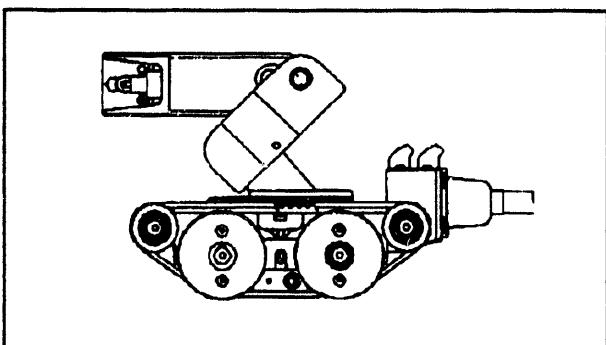


Figure 4.5. Internal Duct Characterization System Concept.

TECHNOLOGY NEEDS

Throughout 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 from duct work, much of which is inaccessible due to its

location in concrete or running through hot cells. Duct work characterization is extremely difficult because of varying size and direction of travel. Characterization of duct work is essential before, during, and after D&D activities. Identifying portions of ducts that are not contaminated greatly reduces the amount of material sent to waste handling facilities and decontamination. Conventional methods have been applied to duct work with some success, but at the risk of human exposure to high levels of contamination. Limited capability remote duct work characterization systems are commercially available. A robotic/remote duct characterization system with extended travel capability is needed that can perform chemical and radiological contaminant characterization and select hot spot decontamination or partial duct work dismantlement.

ACCOMPLISHMENTS

This activity is being initiated in FY94. Future accomplishments are expected to include:

- Requirements and procurement specifications for the duct work characterization system will be developed in the first half of FY94.
- An industry procurement for the duct work characterization system is expected in the second half of FY94.
- Upon delivery of a system, testing and evaluation of the system will be performed.

COLLABORATION/TECHNOLOGY TRANSFER

This technology is being developed by the Idaho National Engineering Laboratory. It is currently expected that this activity will develop a procurement specification for an industry procurement for the basic duct work characterization system. Industrial involvement is desired to provide commercial availability of the system.



**For further information, please
contact:**

William Hamel, PhD

D&D Coordinator

Oak Ridge National Laboratory

(615) 574-5691

Mark D. McKay

Technical Lead

Idaho National Engineering Laboratory

(208) 526-5211



Robotics Cross Cutting and Advanced Technology

Section 5.0

5.0

ROBOTICS CROSS CUTTING AND ADVANCED TECHNOLOGY

Several program elements within the Robotics Technology Development Program have some degree of common technology needs. These common needs, plus the increasing need for technologies that can be directly applied to faster, safer, better and cheaper robotics systems, are the main focus of the Cross Cutting and Advanced Technology Team. The FY94 Program addresses seven technology areas:

- Controls
- Sensing Systems
- Technology Transfer
- System Analysis
- Simulation
- Cooperating Multi-Arm Manipulation
- University Research and Development

The CC&AT Program is coordinated by Sandia National Laboratories, with participation by Pacific Northwest Laboratory, Los Alamos National Laboratory, and Oak Ridge National Laboratory.

The CC&AT University Program currently has fourteen university participants. There are also industry partners participating through contracts and Cooperative Research and Development Agreements.

Several of the CC&AT technology areas are presented in more detail in the following chapter and include specific points of contact. SNL contacts for the CC&AT Program are Dr. Raymond Harrigan, Lead Technical Coordinator, and Daniel S. Horschel, Alternate Coordinator.

5.1

COOPERATING MULTI-ARM MANIPULATION

TASK DESCRIPTION

There are many instances within DOE of remotely-driven processes that could benefit from the use of two manipulators for remote handling or remediation activities when using robotic systems. To date, much of the work on dual arms has focused on two similar arms. The RTDP's Cross Cutting and Advanced Technology (CC&AT) Team will continue this approach, but also begin to look at dissimilar arms (hydraulic and electro-mechanical) and varying levels of multiple cooperating robots.

This effort will continue to develop generic technologies that can be used for the control and cooperation of multiple arm robotics systems. Efforts of university researchers, through their university R&D program, are being incorporated into the control algorithms used within the RTDP and then transferred to other RTDP task areas.

In addition, future areas of development will include dexterous, general purpose end effectors to support the need for enhanced manipulation in remote environments. Current robot end effector technologies typically support only parallel jaw grippers. Multi-fingered hands which support fine manipulation are needed in most all waste cleanup scenarios handling hazardous materials. It is anticipated that a design effort which identifies critical manipulation skills will begin with the university R&D sector, followed by a cooperative university/laboratory development activity.

TECHNOLOGY NEEDS

The use of two robot arms will be essential for many of the intrusive activities required in the selective retrieval of hazardous components in a decommissioned facility or to handle and resize the vast array of buried waste objects. For safety reasons, it may be required for one arm to hold an object while the second arm cuts the object free. This procedure also has the benefit of providing structure in the robot's workcell, which will speed operations. Two arms also allow operations to proceed more expeditiously in both characterization and retrieval activities. The combination of screening tank waste or soil with one manipulator while a second arm performs retrieval activities results in faster, safer, and cheaper remediation activities since there will not be the necessity to constantly change end effectors. Many other scenarios exist that would benefit from the use of two dexterous arms being simultaneously deployed. This task develops those generic technologies for multi-arm control to be applied to the specific needs of RTDP technical areas.

ACCOMPLISHMENTS

Much of the work to date in the controls area in CC&AT can be characterized as developing the enabling (or cross cutting) technologies to allow rapid advances to be made. A key element of the work to date has been to develop controls technologies which support the rapid

integration of advanced technologies as they become available. This has been accomplished largely through the use of reusable software modules for the control of robot systems that were developed by the RTDP. The software tool kit is collectively known as Generic Intelligent System Controller-Kit (GISC) software. The modular nature of the software allows for easy reuse, as well as easy expansion and integration of new technologies. During FY93, the GIS-Kit software development for dual-arm manipulation began and continues in FY94. Efforts for task sequence control, supervisory control, advanced path planning, and automated generation of robot programming will be continued. The goal is to provide an intelligent controls environment that integrates the operator as a supervisor rather than a provider of detailed controls instructions.

Advances in low-level control algorithms for dual-arm manipulation are incorporating the vast research done at universities on this research area.

University expertise to bear on this technology area. The principal investigators, Prof. Tzyh-Jong Tarn, with the support of Antal K. Bejczy, are supporting this effort. This team approach encourages leading experts to work on the same problem, so the results can be rapidly applied to the needs across the DOE Complex.

For further information, please contact:

Ray Harrigan, PhD
CC&AT Coordinator
Sandia National Laboratories
(505) 844-3004

Dan Horschel
CC&AT Alternate Coordinator
Sandia National Laboratories
(505) 845-9836

Robert Palmquist
Sandia National Laboratories
(505) 844-2552

William Hamel, PhD
D&D Coordinator
Oak Ridge National Laboratory
(615) 574-5691

Dennis Haley
ORNL
(615) 576-4388

COLLABORATION/TECHNOLOGY TRANSFER

The research areas of multi-arm manipulation are being addressed in CC&AT, while application of the technologies are sponsored by the specific programs that have need for dual arm manipulation, such as Decontamination and Dismantlement, Tank Waste Retrieval and Buried Waste remediation activities.

As part of CC&AT, a University Research and Development effort was established at Washington University in St. Louis, MO to bring

TASK DESCRIPTION

There is a large number of technology options available for waste site cleanup. 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. This task is devoted to developing the tools necessary to analyze systems within the RTDP and applying them internally to help guide the technologies developed and pursued by the DOE.

TECHNOLOGY NEEDS

Due to the hazardous nature of many waste sites, human entry will be proscribed. Past experience has shown that the use of conventional remotely operated equipment is tedious and slow (frequently 8 to 50 times longer than similar hands-on task execution times). The economic costs and benefits of computer assisted robotic devices need to be evaluated to maximize 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 RTDP requires the development of general techniques for application to the evaluation of all robotics technology development efforts. The RTDP Cross Cutting and Advanced Technology Group focused early on development of cost/benefit analysis tech-

niques based upon sound life cycle cost assessment approaches. These cost/benefit analysis techniques are then applied generally within the RTDP to guide development activities.

ACCOMPLISHMENTS

Sandia National Laboratories (SNL) developed a generalized cost/benefit analysis approach for use by the RTDP team. Factors that are analyzed include the costs of human-supervised robotic systems and benefits, such as reduced radiation exposure, reduced operating and life cycle costs, and increased safety. The RTDP applies these tools and further develops them. The results from the application of the systems analysis tools are used to review all RTDP projects and integrate information from each to provide DOE with a first analysis of the projects to evaluate potential costs and benefits using life cycle costing techniques.

SNL has performed several systems analyses evaluating the cost/benefit of applying robots to selected ER&WM applications. The most complete analysis evaluated the application of robotics technology to the handling of Trupact containers at the Waste Isolation Pilot Plant (WIPP). This analysis showed that robot systems were typically more cost effective than manual Trupact unloading due to the speed of automated robot systems and the reduction of operator exposure to radiation to near zero. Unquantified benefits of the robot system included automation of the Quality Assurance

audit trail and higher quality of operations due to the repeatability of robot operation resulting from elimination of human errors. Further results of this systems analysis are contained in:

M. W. Edenburn, "Analysis Comparing Robotic to Human TRUPACT Unloading at WIPP", SAND91-0728, Sandia National Laboratories, Albuquerque, 1992

COLLABORATION/TECHNOLOGY TRANSFER

Future work in the area of systems analysis will involve the continued development of tools to set priorities and guide the development of technologies. While it is expected that the cost/benefit analyses performed as part of the RTDP application areas will guide the selection of application areas on which to focus, the CC&AT Systems Analysis Thrust will be focused on developing analytical cost/benefit tools to select which robot technology development areas to focus on first.

Examples include using systems to evaluate the cost/benefit impact of new operator interfaces. The goal is to evaluate and set technology development activities and funding priorities based upon an integration of cost/benefit analyses and engineering experience instead of mere engineering insight.

For further information, please contact:

Ray Harrigan, PhD
CC&AT Coordinator
Sandia National Laboratories
(505) 844-3004

Kathy Erickson
Sandia National Laboratories
(505) 844-0146

5.3

ROBOT SYSTEM SIMULATION

TASK DESCRIPTION

This task was initiated in FY94 to develop and use techniques for simulation of a robot system using verified algorithms and models. Validated simulation tools are needed for the design and evaluation of unique and costly robot systems that are envisioned for the remediation activities of the DOE Complex. The task will result in a library of simulation modules that can be easily selected and integrated to allow the DOE and the national labs to simulate and evaluate performance and design parameters of a robot system before it is purchased or committed to hardware. The completion of this task will enable advanced robot systems to be designed faster and will help ensure that the design selected and fabricated is the best design for the requirements of the remediation task.

to validate simulations dealing with dynamic and adaptive control of a flexible manipulator.

Through the use of the testbed, the RTDP researchers will be able to assess one entire system, and with minimal hardware modification, some additional variations as to performance and controllability issues can be addressed. This simulation task will provide DOE researchers with tools that can be used to influence design and assess system performance before costly modifications are made or new systems are acquired. Full capabilities of the simulation tools will be made possible by validating the simulation modules to real hardware systems, such as the RTDP long reach arm testbed, and then applying validated simulation tools to conceptual and prototype designs.

TECHNOLOGY NEEDS

Some of the robot systems required for the remediation of the DOE sites are truly unique and are estimated to cost millions of dollars for the robot hardware alone (specifically excluding management and balance of plant costs). Design and analysis tools that can model structural performance, control behavior, task suitability, and the interaction of end effectors do not exist in one integrated package, and many key simulation parameters unique to these robots do not exist at all. As robot systems are purchased by the DOE, the need to evaluate vendor proposals becomes more acute as the systems become more costly and unique. Further, the RTDP is developing a testbed for the arm-based retrieval technology development. This testbed, among other things, will be used

ACCOMPLISHMENTS

This is a new task, but has had some support through the CC&AT Program in past fiscal years for some of the initial modules that will be used in the simulation libraries. This task is influenced by past efforts on graphical and model based robot control and the advances that an intelligent supervisory control system can accomplish.

A means to model sensor and model based control approaches will be investigated for their feasibility for incorporation into the simulation module library. Past efforts by the RTDP in graphical robot programming will serve as a foundation for the incorporation of new control schemes and can extend to the use of fuzzy logic controllers and learning algorithms being incorporated and tested in simulation.

Simulation of other aspects of the robot system will also be pursued. The incorporation of advanced path planning and automatic programming of the robots systems can be used as a development tool for advanced controls and automation of tasks through machine intelligence.

Initial efforts for the completion of this task will go toward prioritization of simulation needs within the RTDP task areas (see Figure 5.3.)

efforts will build on the rich visualization tools available through industry and universities. These tools will be extended and integrated to develop a robust library of tools that can be used as design and evaluation tools for DOE researchers. As the simulation tool library matures, specific tools or the entire library would logically be transferred to the robot manufacturers for their use as design and evaluation tools.

COLLABORATION/TECHNOLOGY TRANSFER

Collaboration among RTDP participants will extend to further include the university researchers as their work applies to the simulation task and the use of inter-laboratory high-speed data communications to foster team development and application of the simulation and validation activities. Industrial partnerships will also be encouraged. Initially, simulation

For further information, please contact:

Fred Oppel

Sandia National Laboratories
(505) 844-7929

Daniel Horschel

Sandia National Laboratories
(505) 845-9836



Figure 5.3. WYSIWYG Robot. What-you-see-is-what-you-get. The computer graphic representation precisely follows the motion of the robot and its environment.

5.4 UNIVERSITY RESEARCH AND DEVELOPMENT

TASK DESCRIPTION

Sandia National Laboratories coordinates CC&AT development, one of the elements of the Robotics Technology Development Program within the Office of Demonstration, Testing and Evaluation of OTD. A major goal of CC&AT is to develop broadly applicable robotic technologies to improve safety while reducing time and cost for hazardous and radioactive waste clean-up.

In support of this goal, the RTDP, through Sandia, issues periodic requests for proposals to the university community for needs-based research at the forefront of robotics technology. Also each year, the previous year's university-based research is reviewed, and projects that have produced important results and continue to support RTDP needs are extended. The University Research and Development Program has been in existence for two years. Fourteen research projects are currently funded. It is the intent of the OTD RTDP to extend this program to approximately twenty projects.

TECHNOLOGY NEEDS

In 1991, needs were established by the RTDP team members in the areas of:

- robotic system failure mode analyses;
- impact of kinematic and actuator redundancy on robot systems reliability and safety;
- whole arm sensing for collision prevention;
- subsurface mapping of waste sites;

- hardened micro-sensors for robot control;
- software safety; and
- algorithms for the stable control of large robot manipulators subject to structural vibrations.

Responses to the request for proposal come from the leading robotics schools in the country. University projects funded in 1991 were proposed by: Rice University; The University of Wisconsin; New Mexico State University; Case Western Reserve; The University of Florida; Purdue University; Carnegie-Mellon University; The University of Tennessee; and Georgia Institute of Technology.

In 1992, the University Research and Development Program was expanded to address six other RTDP identified needs:

- modular robotic systems;
- applications of virtual reality concepts to robot system control;
- dual manipulator cooperative control;
- icon-based software programming;
- control of force-reflecting telerobotic systems; and
- real-time servo control using computer vision.

Universities represented in 1992 included:

Washington University; Carnegie-Mellon University; University of Tennessee; University of Minnesota; and Pennsylvania State University.

In 1993, the University Research and Development Program was expanded to address the need of machine health monitoring.

Universities represented in 1993 included Colorado School of Mines.

The University Program is expected to grow from two to five more technical needs areas during 1993 and 1994.

ACCOMPLISHMENTS

University researchers have been supporting needs that cut across the RTDP programs and specific task areas. Some of the needs being addressed by the university programs are safety and reliability issues related to placing robotic systems in a hazardous environment. These needs are being addressed by five programs:

- impact of kinematic and actuator redundancy on robot system reliability and safety;
- fault tree analysis of robot systems;
- software safety;
- hardened micro sensors; and
- machine health monitoring.

The efforts of these universities to address safety issues unique to the cleanup of the DOE Complex have been demonstrated on robot systems at the national labs, allowing the research to be rapidly applied to the demonstration systems developed by the RTDP. Similar progress is being made in the incorporation of servo control code for dual arm manipulation, modular robotics, control of force-reflecting telerobotic systems, and algorithms for control of large robot manipulators, which have application to several RTDP task areas, including Tank Waste Retrieval, Decontamination and Dismantlement, and Buried Waste.

Some of the university programs support a more specific need in the RTDP. For example, New Mexico State University is applying data

interpretation algorithms to geo-physical sensor data to develop detailed subsurface maps of objects; these maps have the most direct insignificant impact to the cleanup of buried waste sites. This program has been using real geo-physical data collected from INEL and SNL sites.

The University Program has resulted in a close collaboration between the national labs and the university researchers, with the technical expertise of both institutions focused on the needs in the DOE Complex with two important goals:

- new technologies applicable to DOE and national site cleanup; and
- advanced research and development capabilities in the form of degreed researchers, enhanced laboratory capabilities, and an increased knowledge base.

These result in rapid technology transfer from sources to the field and reduced development time and costs.

COLLABORATION/TECHNOLOGY TRANSFER

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 site cleanup needs. The CC&AT team members include representatives from Pacific Northwest Laboratory, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, and Sandia National Laboratories. The announcement of a pending RFP is published in the Commerce Business Daily (and faxed or mailed to Sandia's mailing list) during the second quarter of the fiscal year (January to April). RFPs are mailed in re-

sponse to inquiries, and formal proposals are usually required by mid-June. Selection of proposals to be funded in each category is made as soon as possible thereafter, with contracts usually being placed by mid-August.

To be placed on SNL's university R&D direct mailing list, researchers should contact **Darla Tyree**, SNL, Organization 02101, Box 0322, Albuquerque New Mexico 87185-0322.

For further information, please contact:

Jerry Stauffer

Intelligent Systems and Robotics Center
Sandia National Laboratories
(505) 845-8966

TASK DESCRIPTION

This task develops integrated sensing systems needed for the successful operation of more efficient, safer, and cost-effective robotics systems for application to hazardous waste cleanup. Sensor systems under development include sensors associated with the real-time safe control of robots and integrated modular sensor systems for providing maps of the robot's work environment, which can be used to automatically guide robot operations and monitor operator commands for safety. This task focuses on integration of existing sensors with robotic systems and develops only those sensors unique to robotic needs not under development elsewhere.

Significant enhancement to the safety of remote operations can be achieved if sensor systems can be developed that detect potential collisions between robots and objects in the robot's work space. Sensors are being developed that create a field around a robot and can sense the approach of an object. Highly modular capacitance based sensors which can be easily attached to robot manipulators are under development, together with microelectronic interfacing technology to allow easy deployment on a wide variety of robot platforms.

In addition, integrated compact sensor systems which can be deployed using robotic systems are under development in a project termed *MiniLab*. A "plug-and-play" architecture allows chemical, radiological, and physical sensors to be rapidly reconfigured according to site needs. Laser based geometry sensing systems allow computers to automatically program robots to complete operations

while avoiding collisions. Accurate robotic deployment of these sensor systems allows correlation of multiple sensor scans using statistical techniques to extract information not available from either single sensor readings or uncorrelated scans. The major emphasis in future development activities within this task focuses on such sensor fusion and automated data interpretation.

TECHNOLOGY NEEDS

Remote operations in hazardous waste sites must be performed quickly and safely. Unfortunately, experience with remote manual operations indicates that these operations are slow, and operator tedium can lead to reduced safety. Remote equipment sensors alert operators to potentially unsafe operations or movements which could cause inadvertent collisions with, for example, risers in underground storage tanks. In addition, sensors gather information about remote environments to provide maps which can be used to verify the safety of operator commands and automate certain tedious repetitive operations. Finally, sensors allow safe contact of remote equipment, such as long reach robot arms, with objects and materials in hazardous environments.

ACCOMPLISHMENTS

- A prototype integrated *MiniLab* sensing system for robotic mapping of waste environments has been developed and demonstrated using plug-and-play sensor integration technology.

- Whole arm sensing technology has been developed and demonstrated to provide automated collision avoidance on robot manipulator systems.
- Structured lighting technology has been developed and demonstrated for mapping surfaces in hazardous waste environments such as the Fernald waste storage tanks.
- Automated data fusion and interpretation algorithms utilizing robotic positioning capabilities are under development.

COLLABORATION/TECHNOLOGY TRANSFER

- A Commerce Business Daily announcement was released in FY93 which resulted in a list of commercial partners interested in CRADAs for commercializing MiniLab technologies.

- A CRADA has been initiated with Merritt Systems Inc. for sensor-based collision avoidance technologies.
- A CRADA is in place with Mechanical Technology Inc. to commercialize laser-based structured lighting technology for mapping of surfaces in waste sites.

For further information, please contact:

Perry Molley

Intelligent Systems and Robotics Center
Sandia National Laboratories
(505) 844-2627

Barry Spletzer

Intelligent Systems and Robotics Center
Sandia National Laboratories
(505) 845-9835

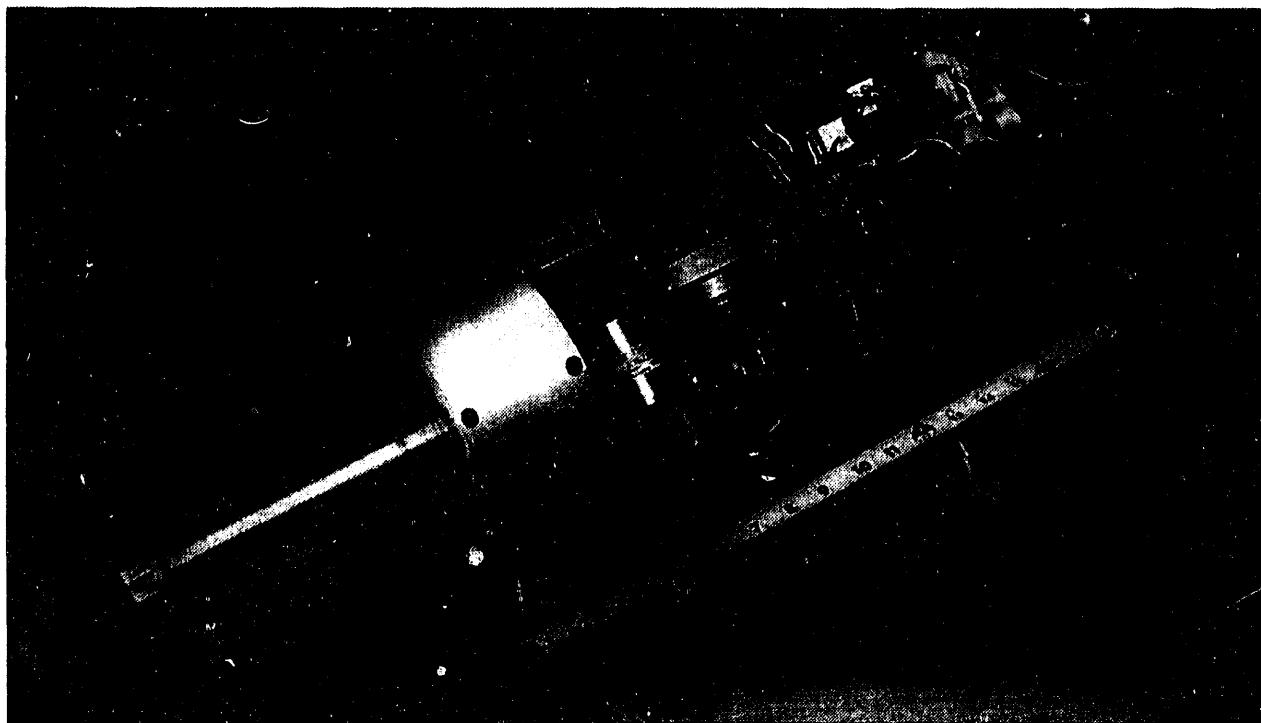


Figure 5.5. Integrated Compact Sensor Systems.

TASK DESCRIPTION

This task develops advanced control approaches for application to robotic systems used in the remediation of DOE waste sites. Particular attention is directed to the development of a Generic Intelligent System Control (GISC) approach which allows for the development and reuse of highly modular software in many diverse projects. Software libraries which can be accessed electronically and used to rapidly implement advanced control systems is a key activity. Documentation and training classes are available.

The GISC approach shown schematically in Figure 5.6 integrates computer models of the robot and its environment with real-time sens-

ing to automate tasks where possible while allowing seamless transfer to operator control when needed. Operator commands are continually monitored for safety by the computing system, and potentially hazardous operations are automatically interrupted. Intuitive graphic interfaces allow remediation technicians with little programming experience to safely and easily program remote cleanup operations. Graphical previewing of intended robot actions allows operators to see and change robot movements before they occur, if desired. Automation of tedious operations greatly speeds remote operations, and task sequence control allows the coordination of the operation of many different pieces of equipment to accomplish complex tasks rang-

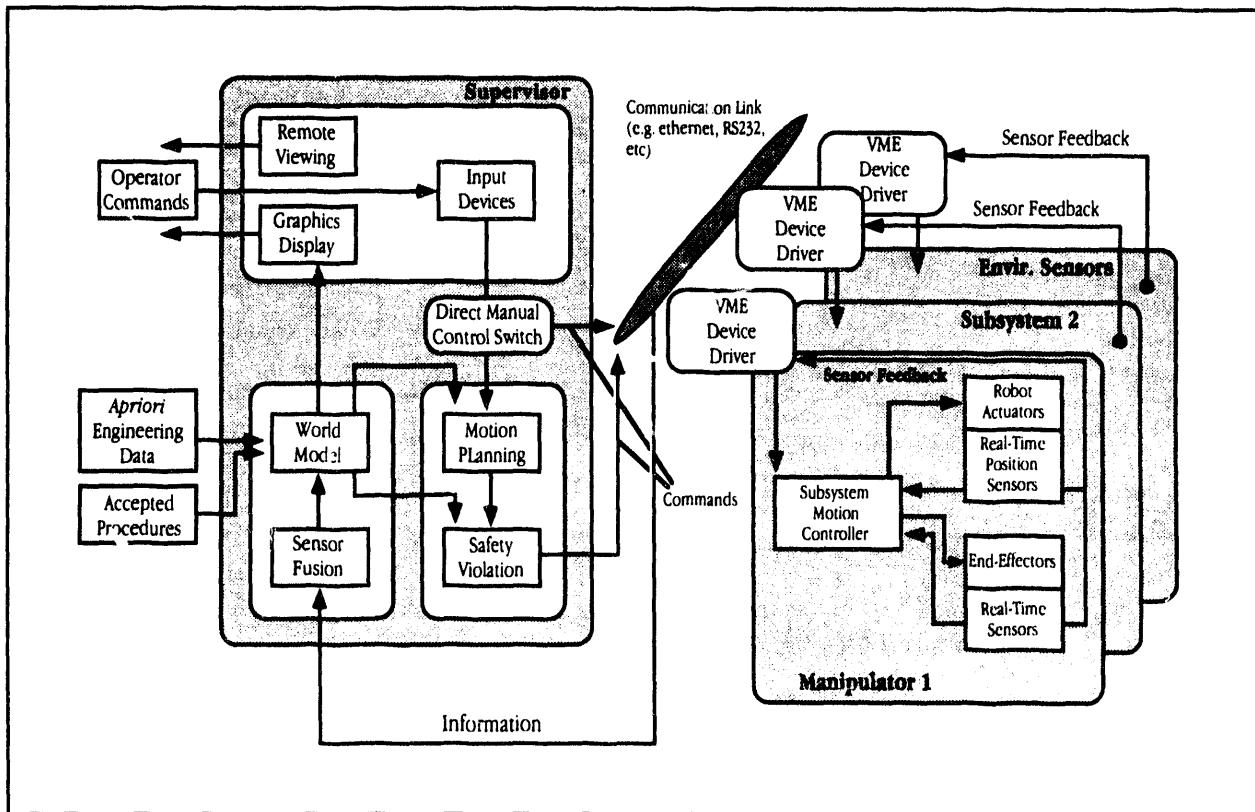


Figure 5.6. The Generic Intelligent System Control Approach.

ing from waste retrieval to contaminant analysis automation in laboratory environments.

TECHNOLOGY NEEDS

Many operations associated with waste site characterization and cleanup will be performed remotely in order to reduce the exposure of remediation technicians to hazards. Traditional remote manual technologies are frequently slow and tedious, leading to errors and accidents. Technology is needed to assist operations personnel by automating tedious tasks, ensuring safety and adherence to standard operating procedures, and reducing time and costs required to complete remote operations.

Modular systems control technologies are needed to combine existing remote handling technologies into integrated systems capable of solving difficult waste cleanup tasks. This technology needs to be highly modular to support insertion of new technologies as they become available; one of the features of plug-and-play system integrates systems with new capabilities by removing old modules and plugging in new ones without extensive rework to the rest of the system. Reuse of well-characterized software modules improves software reliability. Advanced operator interfaces which allow remediation technicians to easily use remote systems safely and without extensive training are needed to allow sites with waste cleanup needs to access the best technology available. Computer algorithms which automatically plan and program robot operations while allowing operators to maintain supervisory control are key to faster and safer remote operations.

ACCOMPLISHMENTS

- Generic Intelligent System Control approach is defined and utilized on multiple application area demonstrations, including waste retrieval from tanks, waste facility operations, decontamination and dismantlement, and contaminant analysis automation.
- Advanced operator interfaces demonstrated:
 - graphical programming which allows nonprogrammers to safely operate large integrated robot systems
 - force reflection which allows operators to feel forces generated during robot operations
- Libraries of modular, reusable software (termed GISC-Kit) available and extensively used within RTDP.
- Documentation available and hands-on interactive classes taught.
- Advanced robot control algorithms for automated oscillation damping.
- Advanced electronic networking technologies under development to increase software sharing and team-based development.

COLLABORATION/TECHNOLOGY TRANSFER

All integrated system projects performed within the RTDP are team-based involving multiple laboratories and industry. The generic systems control environment provided by the GISC approach and extensive reuse of control software stimulates such collaborative technology development and speeds the

implementation of large integrated demonstration systems. Multiple laboratories contribute to the GISC-Kit stimulating growth in the software libraries.

Commercial interest in the GISC approach is keen, thus stimulating transfer to the industrial sector. Basic graphical programming technologies are transferred and available commercially. In addition, a CRADA has been initiated to further commercialize GISC software and provide commercial sources for this technology. Licensing agreements with commercial bridge crane suppliers are under discussion to transfer technology which allows crane operations without payload oscillation.

For further information, please contact:

Daniel Horschel

CC&AT Alternate Coordinator
Sandia National Laboratories
(505) 845-9836

Robert Palmquist

Intelligent Systems and Robotics Center
Sandia National Laboratories
(505) 844-2552

5.7

INFORMATION ARCHITECTURE FOR ROBOTIC SYSTEMS

TASK DESCRIPTION

This task develops the architecture needed to communicate information to integrate heterogeneous components and subsystems into integrated intelligent robotic systems. The GISC project has led to the development of an information architecture in which a client/server approach is used to couple individual subsystems with a computerized knowledge base. The client/server approach is based upon sound fundamentals of modern computer science in which a knowledgeable supervisor (the client) communicates requests for action to devices and subsystems (servers) over an electronic communication network. Subsystems communicate information back to the system's knowledge base so that the supervisor always has up-to-date information upon which to plan and coordinate system operation (see Figure 5.7).

System-level information used by the supervisor is captured in the form of computer models and used to coordinate the operation of diverse subsystems to provide integrated system solutions to difficult problems. Each subsystem also has its own knowledge in the form of computer models (e.g., algorithms for servo control of motors) which enables it to perform functions. An electronic network forms the information highway connecting each subsystem to the knowledge base and to each other. High speed communication protocols convey information from the knowledge base to individual subsystems, as well as allowing sharing of information among modules. Standard commands and instructions are translated into subsystem specific instructions by device drivers in much the way computer networks link diverse computers and peripherals.

Because the GISC approach builds upon modern computer networking technologies, distributed systems can be easily synthesized. As higher speed networking technologies are developed in pursuit of nation-wide goals such as national information infrastructures, the underlying cli-

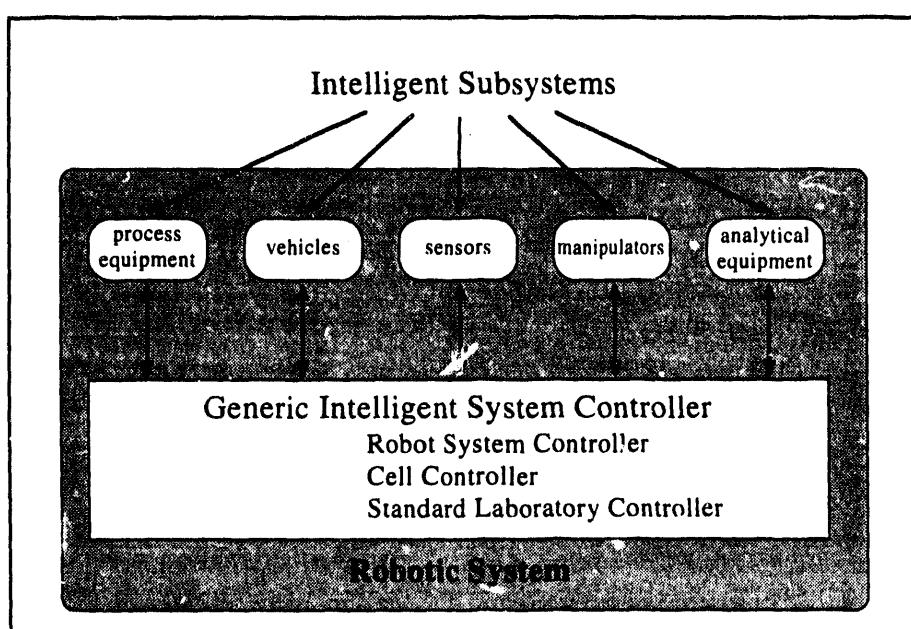


Figure 5.7. Generic Intelligent System Control Integration.

ent/server approach of the GISC approach embraces these new technologies and keeps pace with innovation at minimal development costs to the RTDP.

TECHNOLOGY NEEDS

Robotic systems needed for the cleanup of hazardous waste sites will be integrated systems of diverse devices and subsystems. Information in the form of computer models will be used both to automate repetitive and tedious operations and assist human operators in the performance of difficult remote operations to ensure safety and adherence to standard operating procedures. An information architecture which connects and coordinates the operation of these diverse system elements through the use of computer models is needed.

Since the GISC approach is based upon a client/server information architecture, it also stimulates the development of modular technologies which plug-and-play (through the use of standard device driver interfaces). This meets the need of site remediation technologists for system approaches which can be easily adapted to site specific needs. Essentially the information in the supervisor's knowledge base is updated, the proper subsystem modules connected to the network, and rapid system implementation is achieved.

Finally, the GISC information approach allows integrated technology development to take place at widely separated sites and laboratories without affecting the system information architecture. Thus, teams of developers can network together over national electronic highways, work together, and then deliver technologies to site applications. The size of the net changes, but not the basic system technologies.

ACCOMPLISHMENTS

- Generic Intelligent System Control information architecture approach has been defined and utilized in multiple demonstrations involving team-based technology development. Multi-laboratory technologies have been successfully integrated into large robotic systems addressing many hazardous waste handling areas including waste retrieval from tanks, waste facility operations, decontamination and dismantlement, and contaminant analysis automation.
- Automation of hazardous waste handling tasks using computer models of application information has been demonstrated in prototype test application environments.
- Laboratory tests of the GISC information-based approaches have shown that, with computer assistance, operators with little formal training in robotics can quickly and safely perform difficult remote manual operations.
- High-speed electronic networking of Sandia, Oak Ridge, and Pacific Northwest National Laboratories is underway to increase software sharing and team-based development.

COLLABORATION/TECHNOLOGY TRANSFER

Commercial interest in the GISC information-based approach to robot system integration is high, thus stimulating transfer to the industrial sector. A CRADA was initiated to further commercialize GISC software and provide commercial sources for this technology. All RTDP projects share in the development and application of the GISC approach and contribute reusable software modules to speed technology development.

For further information, please contact:

Ray Harrigan, PhD
CC&AT Coordinator
Sandia National Laboratories
(505) 844-3004

Daniel Horschel
Intelligent Systems and Robotics Center
Sandia National Laboratories
(505) 845-9836

How To Get Involved

Section 6.0

**The Central Point of Contact for all Technology Activities for
the Robotics Technology Development Program is:**

Dr. Linton W. Yarbrough
Robotics Program Manager
U.S. Department of Energy
Washington, D.C. 20585-0002
(301) 903-7293

6.0

HOW TO GET INVOLVED

WORKING WITH THE DOE OFFICE OF ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT

DOE provides a range of programs and services to assist universities, industry, and other private-sector organizations and individuals interested in developing or applying environmental technologies. Working with DOE Operations Offices and management and operating contractors, EM uses conventional and innovative mechanisms to identify, integrate, develop, and adapt promising emerging technologies. These mechanisms include contracting and collaborative arrangements, procurement provisions, licensing of technology, consulting arrangements, reimbursable work for industry, and special consideration for small business.

Cooperative Research and Development Agreements (CRADAs)

EM will facilitate the development of subcontracts, R&D contracts, and cooperative agreements to work collaboratively with the private sector.

EM uses CRADAs as an incentive for collaborative R&D. CRADAs are agreements between a DOE R&D laboratory and any non-Federal source to conduct cooperative R&D that is consistent with the laboratory's mission. The partner may provide funds, facilities, people, or other resources. DOE provides the CRADA partner access to facilities and expertise; however, no Federal funds are provided to external participants. Rights to inventions and other intellectual property are negotiated between the laboratory and participant, and certain data that are generated may be protected for up to 5 years.

Consortia will also be considered for situations where several companies will be combining their resources to address a common technical problem. Leveraging of funds to implement a consortium can offer a synergism to overall program effectiveness.

Procurement Mechanisms

DOE EM has developed an environmental management technology development acquisition policy and strategy that uses phased procurements to span the RDDT&E continuum from applied R&D concept feasibility through full-scale remediation. DOE EM phased procurements make provisions for unsolicited proposals, but formal solicitations are the preferred responses. The principle contractual mechanisms used by EM for industrial and academic response include Research Opportunity Announcements (ROAs) and Program R&D Announcements (PRDAs). In general, EM Technology Development uses ROAs to solicit proposals for R&D projects and PRDAs for proposals for its DT&E projects.

EM uses the ROA to solicit advanced research and technologies for a broad range of cleanup needs. The ROA supports applied research ranging from concept feasibility through full-scale demonstration. In addition, the ROA is open continuously for a full year following the date of issue and includes a partial procurement set aside for small businesses. Typically, ROAs are published

annually in the *Federal Register* and the *Commerce Business Daily*, and multiple awards are made.

PRDAs are program announcements used to solicit a broad mix of R&D and DT&E proposals. Typically, a PRDA is used to solicit proposals for a wide-range of technical solutions to specific EM problem areas. PRDAs may be used to solicit proposals for contracts, grants, or cooperative agreements. Multiple awards, which may have dissimilar approaches or concepts, are generally made. Numerous PRDAs may be issued each year.

In addition to PRDAs and ROAs, EM uses financial assistance awards when the technology is developed for public purpose. Financial assistance awards are solicited through publication in the *Federal Register*. These announcements are called Program Rules. A Program Rule can either be a one-time solicitation or an open-ended, general solicitation with annual or more frequent announcements concerning specific funding availability and desired R&D agreements. The Program Rule can also be used to award both grants and cooperative agreements.

EM awards grants and cooperative agreements if fifty-one percent or more of the overall value of the effort is related to a public interest goal. Such goals include possible non-DOE or other Federal agency participation and use, advancement of present and future U.S. capabilities in domestic and international environmental cleanup markets, technology transfer, advancement of scientific knowledge, and education and training of individuals and business entities to advance U.S. remediation capabilities.

Licensing of Technology

DOE contractor-operated laboratories can license DOE/EM-developed technology and software to which they elect to take title. In other situations where DOE owns title to the resultant inventions, DOE's Office of General Counsel will do the licensing. Licensing activities are done within existing DOE intellectual property provisions.

Technical Personnel Exchange Assignments

Personnel exchanges provide opportunities for industrial and laboratory scientists to work together at various sites on environmental restoration and waste management technical problems of mutual interest. Industry is expected to contribute substantial cost-sharing for these personnel exchanges. To encourage such collaboration, the rights to any resulting patents go to the private sector company. These exchanges, which can last from 3 to 6 months, are opportunities for the laboratories and industry to better understand the differing operating cultures, and are an ideal mechanism for transferring technical skills and knowledge.

Consulting Arrangements

Laboratory scientists and engineers are available to consult in their areas of technical expertise. Most contractors operating laboratories have consulting provisions. Laboratory employees who wish to consult can sign non-disclosure agreements, and are encouraged to do so.

Reimbursable Work for Industry

DOE laboratories are available to perform work for industry, or other Federal agencies, as long as the work pertains to the mission of a respective laboratory and does not compete with the private sector.

The special technical capabilities and unique facilities at DOE laboratories are an incentive for the private sector to use DOE's facilities and contractors expertise in this reimbursable work for industry mode. An advanced class patent waiver gives ownership of any inventions resulting from the research to the participating private sector company.

EM Small Business Technology Integration Program

The EM Small Business Technology Integration Program (SB-TIP) seeks the participation of small businesses in the EM Research, Development, Demonstration, Testing and Evaluation programs. Through workshops and frequent communication, the EM SB-TIP provides information on opportunities for funding and collaborative efforts relative to advancing technologies for DOE environmental restoration and waste management applications.

EM SB-TIP has established a special EM procurement set-aside for small firms (500 employees or less) to be used for applied research projects, through its ROA. The program also serves as the EM liaison to the DOE Small Business Innovation Research (SBIR) Program Office, and interfaces with other DOE small business offices, as well.

CONTACT

David W. Geiser, Acting Director
International Technology Exchange Division
EM-523
Environmental Restoration and Waste
Management Technology Development
U.S. Department of Energy
Washington, D.C. 20585
(301) 903-7640

EM Central Point of Contact

The EM Central Point of Contact is designed to provide ready access to prospective research and business opportunities in waste management, environmental restoration, and decontamination and decommissioning activities, as well as information on EM-50 IPs and IDs. The EM Central Point of Contact can identify links between industry technologies and program needs, and provides potential partners with a connection to an extensive complex-wide network of DOE Headquarters and field program contacts.

The EM Central Point of Contact is the best single source of information for private-sector technology developers looking to collaborate with EM scientists and engineers. It provides a real-time information referral service to expedite and monitor private-sector interaction with EM.

To reach the EM Central Point of Contact, call 1-800-845-2096 during normal business hours (Eastern time).

Office of Research and Technology Applications

The Office of Research and Technology Applications (ORTAs) serves as a technology transfer agents at the Federal laboratories, and provides an internal coordination in the laboratory for technology transfer and an external point of contact for industry and universities. To fulfill this dual purpose, ORTAs license patents and coordinate technology transfer activities for the laboratory's scientific departments. They also facilitate one-on-one interactions between the laboratory's scientific personnel and technology recipients and provide information on laboratory technologies with potential applications in private industry for state and local governments.

**For More Information about these programs and services,
please contact:**

Claire Sink, Director
Technology Integration Division
EM-521
Environmental Restoration and Waste
Management Technology Development
U.S. Department of Energy
Washington, D.C. 20585
(301) 903-7928

Acronyms

Section 7.0

ADISS	Analytical Data Interchange and Storage Standards
AIM	Analytical Instrumentation Module
CAA	Contaminant Analysis Automation
CAALS	Consortium on Automated Analytical Laboratory Systems
CC&AT	Cross Cutting and Advanced Technology
CMU	Carnegie Mellon University
CRADA	Cooperative Research and Development Agreement
D&D	Decontamination and Dismantlement
DBMS	database management system
DT&E	Demonstration, Testing, and Evaluation
DIM	Data Interpretation Module
DoD	U. S. Department of Defense
DOE	U.S. Department of Energy
EM&WM	Office of Environmental Restoration and Waste Management
EPA	Environmental Protection Agency
FEMP	Fernald Environmental Management Project
GC	gas chromatography
GISC	Generic Intelligent System Control
HCI	Human Computer Interface
IBM	International Business Machines
INEL	Idaho National Engineering Laboratory
ID	Integrated Demonstrations
IP	Integrated Programs
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
MTI	Mechanical Technologies Inc.
MWIP	Mixed Waste Integrated Program
MWO	Mixed Waste Operations
MWTP	Mixed Waste Treatment Project
ORNL	Oak Ridge National Laboratory
OTD	Office of Technology Development
PCBs	polychlorinated biphenyls
PNL	Pacific Northwest Laboratory
PRDA	Program Research and Development Announcement
QA/QC	Quality Assurance/Quality Control
RDDT&E	Research, Development, Demonstration, Testing, and Evaluation
RCRA	Resource Conservation and Recovery Act
RTDP	Robotics Technology Development Program
S&M	surveillance and maintenance
SAM	Standard Analysis Method

SERS	Selective Equipment Removal System
SIMON	Semi-Intelligent Mobile Observing Navigator
SLM	standard laboratory module
SMART	Sequential Modular Architecture for Robotics and Teleoperation
SNL	Sandia National Laboratories
SPM	Standard Preparation Modules
SRTC	Savannah River Technology Center
SWAMI	Stored Waste Autonomous Mobile Inspector
TRC	Transitions Research Corporation
TSC	Task Sequence Controller
TWR	Tank Waste Retrieval
WCF	Waste Characterization Facility
WIPP	Waste Isolation Pilot Plant

The image consists of several black and white geometric shapes. At the top, there are two vertical rectangles side-by-side, with a black rectangle below them. Below this is a large, thick black L-shaped block. To the right of the L-shape is a black rectangle with a small white dot near its center. At the bottom, there is a large black U-shaped block containing a white, rounded rectangular shape with a small black dot in its center.

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