BURIED WASTE
INTEGRATED
DEMONSTRATION
PROGRAM REPORT
The Buried Waste Integrated Demonstration (BWID) supports the applied research, development, demonstration, and evaluation of a multitude of advanced technologies. These technologies are being integrated to form a comprehensive remediation system for the effective and efficient remediation of buried waste. These efforts are identified and coordinated in support of the U.S. Department of Energy (DOE), Environmental Restoration and Waste Management (ER/WM) needs and objectives. This document summarizes previous demonstrations and describes the FY-94 BWID technology development and demonstration activities. Sponsored by the DOE Office of Technology Development (OTD), BWID works with universities and private industry to develop these technologies, which are being transferred to the private sector for use nationally and internationally. A public participation policy has been established to provide stakeholders with timely and accurate information and meaningful opportunities for involvement in the technology development and demonstration process.

DISCLAIMER
This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Disclaimer
References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof.
Points of Contact
Jaffer Mohiuddin, BWID Program Manager
U.S. Department of Energy
Office of Technology Development
12800 Middlebrook Road
Room 466A
Washington, DC 20585
Telephone: (301) 903-7965

George Schneider, DOE-ID BWID Program Manager
U.S. Department of Energy
Idaho Operations Office
785 DOE Place, M.S. 1219
Idaho Falls, ID 83401
Telephone: (208) 526-6789

Kevin Kostelnik, BWID Coordinator
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415-3710
Telephone: (208) 526-9642
E-Mail: KVK @ INEL.GOV
EXECUTIVE SUMMARY

This report summarizes previous demonstrations and FY-94 activities of the U.S. Department of Energy’s Buried Waste Integrated Demonstration (BWID). The mission of BWID is to support development of a multitude of technologies for effective and efficient remediation of buried waste throughout the DOE complex. BWID evaluates, demonstrates, and validates technologies and transfers this information and equipment to DOE and private industry to support remediation planning and implementation.

BWID continues to perform research and evaluation of numerous technologies in the areas of characterization, retrieval, assay, contamination control, and treatment. In the characterization area, the focus is on improving sensitivity, range, response time, and cost of subsurface imaging. In buried waste retrieval, the focus is on precision, remote operations, productivity, and cost. In assay, the focus is on variety of species assayed, sensitivity, portability, response time, and cost. In contamination control, the focus is on fixing the source, controlling the spread of contaminants, compatibility with other operations, and cost. In the treatment area, the focus is on process robustness with regard to input waste diversity, effectiveness of the treatment, verification of the process, and the cost.

BWID is investing significant resources to accomplish these objectives. Expenditures were $16 million in FY-92, $14 million in FY-93, and are budgeted at $22 million in FY-94.

BWID has obtained the support of universities, private industry, and other national laboratories in the development of these technologies. In FY-92, there were 17 industry/university partnerships and nine national laboratory partners. In FY-93, there were 16 industry/university partnerships and six national laboratory partners. In FY-94, there are 23 industry/university partnerships and six national laboratory partners.

Outyear efforts for FY-95 will emphasize maturing the engineering aspects of many of these technologies. A full-scale integrated demonstration is planned for the Idaho National Engineering Laboratory’s Cold Test Pit in FY-95. The focus will be for the diverse technologies to operate together as a system and to perform a simulated site remediation. A limited full-scale hot demonstration with actual radioactive and hazardous material is also anticipated.

BWID is placing increasing emphasis on passing this technology to private industry so that they can respond to requests to remEDIATE specific waste sites in the future.
CONTENTS

ABSTRACT 1
EXECUTIVE SUMMARY 3
PROGRAM OVERVIEW 6
THE DOE BURIED WASTE PROBLEM 8
THE TECHNOLOGY DEVELOPMENT PROCESS 10
PUBLIC INVOLVEMENT 16
TECHNOLOGY TRANSFER 18
SITE CHARACTERIZATION 21
  Rapid Geophysical Surveyor (RGS) 22
  Remote Characterization System (RCS) 24
  BWID Dig-Face Characterization 26
  Nonintrusive Sensing of Environmentally Important Objects 28
  Field Demonstration of Characterization Technologies 30
  INEL Noninvasive Characterization Studies 32
  Very Early-Time Electromagnetic (VETEM) System 34
  Virtual Environment Generation of Buried Waste 36
  High Resolution Imaging Using Holographic Impulse Radar Array 38
  Gravity Field Measurements 40
  Imaging Infrared Interferometer 42
  Platforms for Electromagnetic and Magnetic Sensors 44
  Magnetic and Electromagnetic Geophysical Surveying 46
  Thermal Infrared Imaging System 48
  Noninvasive Characterized Sensing of Buried Objects 50
WASTE CHARACTERIZATION 53
  Rapid Transuranic Monitoring Laboratory 54
  Real-Time Monitoring of Transuranic-Contaminated Dust 56
  Assay of Contaminated Soil from Buried Waste Pits 58
  Radiological and Hazardous Material Measurement System 60
  High-Speed Digital Radiography and Computed Tomography of Waste Drums 62
  Improved Transuranic Waste Assay: CTEN 64
  Active and Passive Computed Tomography Gamma Assay of Radioactive Waste 66
  Electrothermal Hollow Cathode Discharge Spectrometry 68
  Hazardous Waste Separation at RWMC Excavation Sites 70
RETRIEVAL 73
  Contamination Control Unit (CCU) 74
  Fixation of Soil Surface Contamination Using Natural Polysaccharides 76
  Electrostatic Curtain 78
  Overburden Removal 80
  Remote Excavation System (RES) 82
  Retrieval Demonstration 84
  Full-Scale Remote Retrieval 86
  Three-Dimensional Simulation 88
  Cooperative Telerobotic Retrieval 90
  Waste Conveyance and Innovative End Effector 92
  Contaminated Material Excavation Handling and Retrieval System 94
The U.S. Department of Energy (DOE) Office of Technology Development (EM-50) has initiated comprehensive research, development, demonstration, testing, and evaluation programs to provide innovative and emerging technologies and technology systems. This research supports objectives of the DOE Office of Environmental Restoration (EM-40), Office of Waste Management (EM-30), and Office of Facility Transition (EM-60).

In an effort to focus resources and address these opportunities, the Office of Technology Development has developed integrated programs and integrated demonstrations. The integrated program is the cost-effective mechanism that assembles a group of related technologies to evaluate their performance to solve a specific aspect of a waste management or environmental problem. The integrated demonstration is the cost-effective mechanism that assembles a group of related technologies to evaluate their performance individually or as a complete system in correcting waste management and environmental problems.

The Idaho National Engineering Laboratory (INEL), which has a significant portion of the DOE transuranic (TRU) buried waste, has been chosen as the lead site for the Buried Waste Integrated Demonstration (BWID) to demonstrate emerging technologies that offer promising solutions to the problems associated with the remediation of buried waste. BWID addresses the difficult remediation problems associated with DOE complexwide buried waste, particularly TRU-contaminated buried waste.

BWID has implemented a systems approach to the development and demonstration of technologies. This approach encompasses the entire remediation process from characterization to postmonitoring. The development and demonstration of the technology is predicated on how a technology fits into the total remediation process. To address all of these technological issues, BWID has enlisted scientific expertise of individuals and groups from within the DOE complex as well as experts from universities, private industry, and the international community.

The BWID mission is to support development and demonstration of a variety of technologies that may be integrated with other commercially-available technologies to remediate buried waste. BWID evaluates, validates, and demonstrates technologies and transfers this information throughout DOE and private industry to support DOE remediation planning and implementation activities.

To test and evaluate technologies considered for remediating buried waste sites, a simulated cold test pit was created by the INEL in 1988. It consists of five cells with various simulated waste configurations. Additional test cells were added in 1992 to encompass other waste configurations, and a shallow characterization calibration cell was added in 1993. See Appendix A for a description of the Cold Test Pit.

BWID's success will be determined by its ability to address the needs of the DOE Office of Environmental Restoration, Office of Waste Management, and Office of Facility Transition. This determination will be made on the basis of technologies and technology systems provided by BWID in time for inclusion into the record of decision (ROD) process and other required remediation activities. BWID works closely with private industry and universities to encourage the commercialization of developing technologies, while working with stakeholders and regulators to enhance the acceptability of developing technologies.
BWID is using a national approach to demonstrate emerging technologies that may help to solve problems associated with remediation of buried waste at DOE facilities across the country.
The amount of buried waste located throughout the DOE complex as of 1990 is estimated at approximately 3.1 million m³ (DOE Complex Buried Waste Assessment, PNL 8390, January 1993). The DOE sites where this waste is predominantly located are Hanford, Savannah River, INL, Los Alamos, Oak Ridge (X 10), and Rocky Flats. The wastes at these various sites have been buried or stored in several types of structures, including trenches, pits, buildings, and storage pads.

Approximately half of all DOE buried waste was disposed of before 1970 in accordance with the regulations of that time. Disposal regulations at that time permitted the commingling of various types of waste [TRU, low level radioactive (LLW), and hazardous]. As a result, much of the buried waste throughout the DOE complex is presently believed to be contaminated as a result of these disposal practices, which significantly increases the volume of materials requiring remediation.

Typical buried waste includes construction and demolition materials (lumber, concrete blocks, steel plates, etc.), laboratory equipment (hoods, desks, tubing, glassware, gloves, etc.), process equipment (heat exchangers, valves, ion exchange resins, high efficiency particulate air filters, etc.), maintenance equipment (hand tools, cranes, oils, and greases, etc.), and decontamination materials (paper, rags, gloves, plastic bags).

The waste and site characteristics of the INEL Radioactive Waste Management Complex (RWMC) are generally representative of other DOE buried waste sites. Therefore, remediation technology demonstrations performed at the INEL will be transferable for potential applications at other DOE buried waste sites.

In the past, incomplete records were kept, and as a result, the exact nature of the contamination is uncertain. Over the years, some of the waste containing drums and boxes have breached, creating new problems. Some have potentially contaminated groundwater.

These waste disposal sites must be remediated or cleaned up within the existing and evolving statutory and regulatory requirements. These requirements may include the Federal Facility Agreement and Consent Order, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), and other interagency agreements with legally binding milestones.
Random disposal of drums at the Idaho National Engineering Laboratory in 1969 (69 6138)

Early trench burial practice at Oak Ridge National Laboratory (ORNL 41946)
Buried waste presents significant remediation challenges, particularly the waste buried prior to 1970. DOE is committed to remediating the problems that resulted from past disposal practices. The DOE Office of Technology Development (EM-50) supports these efforts to ensure that appropriate technology options are available to accomplish DOE Environmental Restoration and Waste Management (ER/WM) remediation objectives. BWID has developed a strategy based on developing and demonstrating technologies that fit into an overall cradle-to-grave system for buried waste remediation.

BWID focuses on the remedial technology application needs of ER/WM. ER/WM sites from across the DOE complex are frequently assessed. Their needs define remedial technology areas where inadequate, marginal, or no technology exists, and the time frame available to provide input to the remedial decision processes. Technology development and demonstration proposals are solicited and evaluated by BWID to determine their potential to support the ER/WM applications. The time frame prior to ER/WM decision milestones is considered by BWID's window of opportunity for development of more cost-effective and efficient solutions for buried waste remediation needs closely ties into ER/WM scheduled milestones.

The BWID systems approach defines the functions that need to be performed by remedial technologies. A detailed system analysis was initiated in FY92 and is being used to identify and develop high-level systems for the remediation of buried wastes.

Technology development and demonstration activities are sponsored by BWID based on their potential contribution to the overall system as well as individual performance potential. These activities are guided by technical objectives that are derived from the performance needs of the system. During testing, technologies are evaluated against technology-specific performance objectives and high-level system objectives to assess both individual technology performance and impact on the overall system.

Technology performance tests are conducted to evaluate a technology's performance relative to the technical objectives. The performance tests are valuable in obtaining technology-specific data on a technology's effectiveness, implementability, and cost. BWID provides this information to potential end users such as ER/WM to assist them in remedial planning and feasibility studies. As technology data are infused into the ER/WM planning cycle, the probability that the technology will be of benefit to the remediation efforts is enhanced. In this manner, BWID technologies are being either considered for application or are in use by ER/WM. BWID has already contributed to remediation efforts at Hanford, Oak Ridge, INEL, and Los Alamos.

As technology development approaches the demonstration stage, BWID conducts demonstrations in an integrated fashion. This provides a cost-effective method to evaluate the performance of technologies in simulated real-life conditions. These demonstrations provide the opportunity to not only evaluate the individual performance of a technology, but also the performance of all or portions of the complete remediation system.

As mentioned previously, technologies are evaluated against the technical objectives defined by the remediation system and ER/WM needs. Technology evaluations are conducted using guidance similar to the CERCLA Feasibility Study guidance for the detailed analysis of remedial alternatives and technology options. The use of technology evaluation criteria guidance as set forth by CERCLA enhances regulatory and stakeholder acceptance of demonstrated technologies. In FY94, BWID will work with the U.S. Environmental Protection Agency (EPA), Region 10, in developing a uniform testing protocol to further enhance acceptance of BWID demonstrated technologies. Published BWID technology evaluation reports become reference sources for ER/WM decision analyses.
BWID technology development will result in both technology transfer with the private sector and DOE implementation during the next several years.

<table>
<thead>
<tr>
<th>EM 30/40/60 Treatability Studies Remedial Action</th>
<th>FY-92</th>
<th>FY-93</th>
<th>FY-94</th>
<th>FY-95</th>
<th>FY-96</th>
<th>FY-97</th>
<th>FY-98</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPLEMENTATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BWID Technology Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology Prototypes</td>
<td>Fullscale Retrieval Demo</td>
<td>Integrated Systems</td>
<td>Radioactive Retrieval Demo</td>
<td>Integrated Treatment Demo</td>
<td>Radioactive Treatment Demo</td>
<td>Integrated Systems</td>
<td></td>
</tr>
<tr>
<td>Characterization Performance Tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retrieval Performance Tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Treatment Performance Tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste Assay Performance Tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private Sector Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMMERCIALIZATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X93 0250
Buried Waste Remediation Systems
The focus of BWID to date has been the system concept of waste retrieval and ex situ treatment for permanent disposal. This system concept was developed from the strategic remediation planning assumptions established by the INEL E:\W and other E:\W programs. Most technologies sponsored by BWID in FY 92 and FY-93 support technology needs for the retrieval/ex situ treatment remediation system.

As E:\W remediation plans evolve from additional site data and regulatory involvement, strategic planning assumptions are being refined. E:\W is placing increased emphasis on waste stabilization and containment approaches, either as interim or final remedies. Therefore, BWID has developed a system for buried waste site containment and stabilization. In FY 94, BWID is sponsoring several technologies that support remediation needs for the containment and stabilization remediation system. For the FY-95 planning cycle, BWID and E:\W will further define technology needs for this system and request technol-
ography development proposals. BWID technology development and demonstration efforts, combined with commercially available technologies in the containment/stabilization arena will further support ER/WM decision analyses.

BWID is also developing a systems approach for in situ treatment of buried waste. In situ treatment could either lead to retrieval of the treated waste or in situ disposal. This system may offer significant advantages in reducing site risk without the risk posed by waste exhumation. Because technologies in this area are the least developed and there are inherent risks as well as potential for problems, it has been given lower priority at this time. As these technologies mature through other DOE integrated programs, they may be incorporated into BWID for buried waste applications.

In addition to these three primary remediation systems, site-specific ER/WM remedial objectives may result in development of remedial alternatives that combine elements from several systems. BWID has considered many of these alterna

<table>
<thead>
<tr>
<th>FY-93</th>
<th>FY-94</th>
<th>FY-95</th>
<th>FY-96</th>
<th>FY-97</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Excavation - Cold Demonstration</td>
<td>EM 40/50 ORNL Remote Excavation - Hot Demonstration</td>
<td>Fullscale Retrieval Demonstration at Cold Test Pit</td>
<td>EM 40/50 Collaborative Retrieval Hot Demonstration</td>
<td>Technology Implementation Support to Industry, EM30/40</td>
</tr>
<tr>
<td>Manned Retrieval Equipment Performance Tests</td>
<td>Site Characterization &amp; Fullscale Remote Retrieval Performance Tests</td>
<td>Selective Retrieval Demonstration at Cold Test Pit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retrieval Support Technology Demonstrations</td>
<td>Telerobotic Dig Face Characterization &amp; Selective Retrieval Performance Tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site &amp; Dig Face Characterization Technology Development</td>
<td>Waste Assay Technology Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasma Torch Performance Tests</td>
<td>Thermal Treatment Supporting Technology Advancements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arc Melter Performance Tests &amp; Diagnostics</td>
<td>Arc Melter Performance Testing</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Detailed integrated logic diagram for characterization/retrieval/treatment system.
tives when developing the remedial system. As ER/WM remedial planning evolves, BWID will continue to develop its systems approach to assist in selecting and developing applicable technology.

Waste Retrieval and Ex Situ Treatment System
The buried waste retrieval/ex situ treatment system involves characterization of the site, exhuming the waste, and ex situ treatment for disposal of the treated waste form. Characterization is required to define waste boundaries, increase safety of waste retrieval operations, and provide feedstream information for the treatment process. Retrieved waste is packaged and conveyed to a treatment facility. The BWID treatment emphasis is presently on high temperature thermal treatments, although other treatment alternatives are being investigated. Depending on the primary treatment process, pretreatment (sorting and size reduction) may be required. Final waste forms must be assayed to determine compliance with disposal requirements. The final function in this system is to package and transport the final waste form to a disposal facility.

Previous BWID technology development in the site characterization area focused on nonintrusive geophysical technology to determine the boundaries of the buried waste and identify and locate specific waste forms such as drums, large metal objects, and voids. In FY-93, BWID initiated development of the dig-face characterization concept. This technology deploys multiple sensors at the dig-face and integrates the resultant data to provide real-time characterization data to the retrieval operations to increase worker safety and enhance retrieval decisionmaking. For the future, BWID will optimize nonintrusive geophysical sensors and data interpretation to improve upon existing nonintrusive site characterization technology. Dig-face characterization has performed preliminary performance tests on several sensors and will continue development of data integration and interpretation methods while investigating sensor deployment alternatives. Waste assay technology development and demonstration is also being initiated in FY-94. Assay methods for large volumes of either containerized or bulk soil and wastes are being improved. Development work is closely linked to ongoing ER/WM assay operations at the INEL to bring technology improvements to actual operations as efficiently as possible.

Retrieval technology developments in FY-94 are building from the progress achieved in FY-93. Full-scale retrieval operations using remotized equipment will be demonstrated to investigate production and implementation issues. In FY-93, BWID successfully demonstrated the feasibility of using conventional excavation equipment to retrieve and size reduce simulated waste and package in containers for transport. The remote equipment demonstration in FY-94 will build on this experience, as will technology development in the areas of end-effector and automated waste conveyance from the retrieval site. Selective retrieval using dual robotic arms will also be studied in FY-94 to support the system concept of hotspot retrieval. Technology development in support of this concept includes cryogenic cutting and vacuum retrieval.

High temperature thermal treatment performance testing will continue in FY-94. BWID is focusing technology development on plasma arc melter due to the potential for a robust treatment that can produce a high quality waste form from a range of feed streams. Melter diagnostics is also a key task within the plasma arc melter development program.

Technology development efforts in FY-94 within the characterization/retrieve/treatment system are supporting BWID's goal of conducting full-scale integrated demonstrations in FY-95 and 96 to support ER/WM decision analyses. Initially, these integrated demonstrations will be conducted using simulated buried wastes. Retrieval and characterization technologies will be integrated and demonstrated at the INEL Cold Test Pit. Melter demonstrations will be conducted with simulated feeds but integrated with feed pretreatment, offgas, and assay technology improvements under development. Planning is also under way to collaborate with ER/WM in support of treatability studies for actual waste sites. Integrating these emerging

14
technologies with available technologies for treatability studies provides a unique opportunity to collect effectiveness, implementability, and cost data prior to construction of production-scale facilities.

**Stabilization and Containment System**

The objective of the stabilization/containment system is to emplace engineered barriers at the buried waste site to reduce or eliminate migration of radioactive and hazardous contaminants. This system may be used as either an interim or long-term solution, depending on the hazard level posed by the site. This system may also be combined with retrieval of selected hotspots to reduce the overall risk of leaving waste in place. Characterization of the site is necessary to determine the waste and contaminant boundaries for both stabilization/containment and removal of hotspots. Containment actions may include subsurface barriers (vertical and horizontal) and/or capping to control water infiltration and contaminant releases through direct contact or air pathways. Stabilization actions may include grouting the waste/soil matrix to reduce water and contaminant migration through the waste matrix.

BWID is initiating development activity in the containment/stabilization area in FY-94. In situ encapsulation of the soils/waste matrix and confinement of contaminants in the fractured basalt will be the focus of performance tests planned in FY-94. BWID is identifying technology areas within the containment/stabilization area where technology gaps exist and will pursue technology in FY-95 and outyears to fill those gaps. These areas include verification technologies to ensure the waste containment is complete, methods to verify the effectiveness of the stabilized waste matrix in reducing contaminant migration, and methods to emplace waste stabilizing grouts.

**In Situ Treatment System**

The objective of the in situ treatment system varies, depending on the waste form disposition requirements. If the treated waste form must be retrieved for disposal at an onsite or offsite facility, the objective of the in situ treatment is to minimize the potential spread of contamination before and during buried waste retrieval while also being compatible with disposal criteria. Untreated waste retrieval poses significant contamination control problems that may be mitigated through in situ treatment prior to retrieval operations.

If the waste can be left in place following in situ treatment, the objective of the treatment is to produce a waste form that meets the in place disposal criteria for that site. The performance of the in situ treatment technology must provide for the destruction of hazardous waste and immobilization of radiological and toxic metal contaminants. Long-term releases of hazardous and radiological contaminants to the groundwater, air, and soil would have to be eliminated or reduced to acceptable levels. This type of system could also be integrated with a containment system to further reduce contaminant migration potential.

BWID has sponsored limited technology development for in situ treatment systems. In FY-94, BWID will be conducting performance tests of an in situ waste encapsulation technology that would reduce contamination control concerns during waste retrieval operations. This technology would have to only encapsulate contaminants for the time it takes to retrieve and handle the waste. In addition, it cannot interfere with downstream treatment. Pending the results of this preliminary investigation, demonstration of this technique will be conducted in the outyears. BWID will also continue to work with ER/WM to identify other technology needs to support its remediation objectives.
PUBLIC INVOLVEMENT

Public involvement in BWID is critical to successful development and transfer of remedial technologies. Appropriate mechanisms for communication with the public, regulators and elected officials, the private sector, and the university community are being aggressively pursued by BWID to enhance informed public participation in DOE environmental decisionmaking.

BWID has worked aggressively with INEL Public Affairs, Speakers Bureau, and Community Outreach Offices. BWID speakers have appeared before a variety of civic and educational groups, and technology briefings have been included by the Environmental Restoration Public Outreach program prior to public meetings and workshops on INEL documents such as Site Specific Plan and Community Relations Plan update.

BWID technologies have been entered into a DOE database called ProTech. ProTech is an interactive database that provides users with information about DOE sites and remedial technologies, including baseline technologies, cost and time to implement, private industry interaction, and technology comparisons. BWID technology information is regularly updated and expanded as technologies are developed and tested.

Regulators and elected officials will be making decisions about the need to remediate contaminated sites, and the technologies to be used. Without timely and accurate information, informed decisions cannot be made. Close ties have been established with EPA Region 10, and BWID is participating in an effort to establish a uniform testing protocol between EPA and DOE. In 1994, BWID will establish a working partnership with the Western Governors Association to assist the Western States in developing key technology for state remedial action activities.

BWID has expanded its relationship with the university community through site characterization, waste retrieval, and waste treatment technology research and development. In 1994, a greater reliance on the expertise of the university community will be achieved with the establishment of the Technical and Academic Review Group (TARG), which provides expert, independent peer review of technology proposals and test planning.

The private sector is also critical to the success of BWID technology development, testing, and commercialization objectives. Efforts to locate new or innovative uses for existing technologies are enhanced as are opportunities to transfer technologies to the private sector. Requests for proposals have been issued, and proposals have been evaluated, and papers, displays, and poster sessions presented at professional society meetings and other events to encourage private sector involvement.

BWID sponsored a Technology Exhibition and Equipment Display in July 1993. The exhibition provided a forum to enhance the interaction between public and private sectors. Participants included representatives from industry, universities, DOE, and other government agencies. The 1994 Technology Exhibition and Equipment Display will again offer an opportunity to communicate BWID technology demonstration and evaluation progress with each of these publics. Data from demonstrations will be presented and equipment will be available for inspection.
BWID shares its research with the public through displays and presentations at national conferences and meetings.

BWID sponsored a Technology Exhibition and Equipment Display in Idaho Falls in 1993 and plans a similar program in 1994 (93 672 1 33).
Three objectives of technology transfer are integral to BWID technology commercialization and implementation. They include:

- **Technology Infusion.** Transfer of technology from industry, universities, and other Federal agencies for integration into the process.

- **Technology Adoption.** Sharing of demonstrated technology among DOE laboratories, integrated demonstrations, and programs (implementation).

- **Technology Diffusion.** Transfer of demonstrated technology from BWID to industry (commercialization).

A strategy has been developed to meet these technology transfer goals. First, BWID technologies will be assessed according to commercial potential. The assessment will evaluate the technology against business and technical attributes that are important to successful commercialization. Business attributes include competitive advantage, uniqueness, and potential market. Technical attributes include technical complexity, maturation, technical advantage, and scale-up risks. From this assessment, BWID technologies are ranked to determine those with the highest near-term commercial potential, considering both technical and business attributes.

For those technologies emerging from the evaluation with a high potential for commercialization and implementation, an action plan is developed for commercializing the technology. The action plan will include a detailed market assessment for the particular technology, an evaluation of the best method for transferring the technology (Cooperative Research and Development Agreement, license, or spin-off), and a timeline of required steps to commercialize the technology.

Once market needs are thoroughly understood, a technology can be adapted to meet commercial requirements. This approach is called "market pull" and generally results in an efficient and effective commercialization process.

The BWID also works closely with the DOE EM Technology Transfer Network to package and disseminate BWID technology information to industry and end users. Through the Network, BWID interfaces internally with EM-30/40/60, procurement offices, and other DOE technology transfer organizations, as well as externally with businesses, state and local business assistance organizations, and other Federal organizations.

By understanding customer needs, providing a technology to solve customer problems, and forming strategic action plans to transfer the technology, BWID is successful in implementing and commercializing demonstrated technology.
The BWID technology integration process begins with technology infusion and results in technology diffusion.

FY-93 technology activities of the BWID program.
SITE CHARACTERIZATION

Point of Contact
Richard A. Callow
EG&G Idaho, Inc
P.O. Box 1625
Idaho Falls, ID 83415-3710
Telephone: (208) 526-2042
E-Mail: ARC @ INEL.GOV

John Richardson
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415-3710
Telephone: (208) 526-7545
E-Mail: JGR@INEL.GOV
RAPID GEOPHYSICAL SURVEYOR (RGS)

Demonstration of this technology was completed in FY-93

Principal Investigators
Glen S. Carpenter, INEL
Nick E. Josten, INEL
Lyle G. Roybal, INEL

Research Objective
Design, construct, and demonstrate a device to quickly and inexpensively characterize buried waste sites by collecting high quality, dense sets of magnetic data.

Technology Description
The Rapid Geophysical Surveyor (RGS) is a hand-pushed, nonferrous vehicle that carries multiple cesium total field magnetometers, a data logger, and data storage hardware and software. The unit can be easily adapted to accommodate different magnetic sensors. Magnetic data are collected automatically and stored at user-specified intervals as close as 2-in apart as the unit is pushed along survey profile lines. The resulting database is very high resolution and can identify individual metallic objects, object orientation, shape, and depth of burial.

Technology Attributes
The RGS can be used at any DOE or industrial facilities that have buried hazardous waste or radioactive waste. It can perform high resolution geophysical magnetic surveys quickly (30-300 times faster) and more economically (20 times cheaper per data point) than hand held instruments. Quicker and better geophysical surveys can be performed with the RGS at a significantly lower cost.

Waste Management/Remediation Need
This technology can provide a viable geophysical survey of buried waste sites such as the INEL's Radioactive Waste Management Complex (RWMC). It provides a critical data set for waste pits, which results in an estimate of the depth to basalt at pit boundaries, depth to overburden/waste interface, or location of waste and original excavation boundaries.

Accomplishments
The RGS was successfully demonstrated at the Cold Test Pit and then used to scan buried waste at Pits 7 and 9 at RWMC and at Los Alamos National Laboratory. Straightforward interpretation principles were applied to the magnetic data, which provided reliable detection of all the isolated ferrous objects in the Cold Test Pit Characterization Cell, a general depiction of the Retrieval Cell and an accurate definition of the overall waste pit. The RGS can collect spatially denser data sets than previously possible, thereby providing a much higher resolution picture of the buried waste site. The surveyor was developed for less than $200,000.

Research Opportunities
Other geophysical instruments are recommended to be incorporated on this platform. Candidates might be gamma detectors, chemical detectors, and an electromagnetic system.

Technology Transfer
Disclosure of this research to private sector interests via technical journals and presentations at technical conferences are expected to initiate interest in RGS. A patent and licensing agreement are being sought by the inventors.
Rapid Geophysical Surveyor at the INEL Cold Test Pit during the 1993 BWID summer demonstration (93-476-1-13).

**RGS Magnetic Data**
- ~60,000 data points
- 1 ft x 1 ft grid
- 1500 data points/hr

**Conventional Magnetic Data**
- ~525 data points
- 3 ft x 13 ft grid
- 125 data points/hr
REMOTE CHARACTERIZATION SYSTEM (RCS)

Demonstration of this technology was completed in FY-93

Principal Investigators
Norman Hansen, Gerald A Sandness, and Tim L. Stewart, Pacific Northwest Laboratory
Reva A. Hyde and Stephanie Walker, INEL
Ronald Kane and John L. Pence, Lawrence Livermore National Laboratory
Tim E. Noel, Brad S. Richardson, and John Rowe, Oak Ridge National Laboratory
Daniel S. Horschell and Charles Q Little, Sandia National Laboratories

Research Objective
Demonstrate the feasibility of remote, high precision characterization of buried waste by deploying and operating a remote vehicle with multiple geophysical sensors over a waste site

Technology Description
The Remote Characterization System (RCS) consists of a vehicle, multiple geophysical radiation and/or chemical sensors, on-board video cameras, data communication equipment, Global Positioning System, and control base station. The vehicle was designed and fabricated specifically for the RCS to minimize the amount of ferrous metal in the vehicle that would interfere with the operation of the sensors

Sensors include flux gate, proton precession, and optically pumped magnetometers, ground penetrating radar, and an EM-31. Other chemical and radiological detectors may be added to the array. The control system enables integration of subsurface data with excavation planning, controls the vehicle, and has an Ethernet radio frequency link with the sensors and vehicle controls

Waste Management/Remediation Need
This technology could be applied to site characterization for buried waste. It can help locate original excavation boundaries, depth to the basalt at those boundaries, position of buried objects, and depth to the overburden/waste interface

Technology Attributes
The RCS allows simultaneous use of multiple sensors deployed on a remote controlled vehicle with sensor data automatically tagged with extremely accurate position (centimeters), thereby reducing remediation cost by rapidly characterizing waste sites. Because the RCS is remotely operated, it can characterize waste sites that are inaccessible to workers and reduce exposure at accessible hazardous waste sites by not requiring those workers to enter those sites

Accomplishments
The RCS was demonstrated and tested at the INEL Cold Test Pit in June 1993. The RCS, while making numerous advances in the technology of remote site characterization, was shown to be still in the development stage

Research Opportunities
The demonstration test showed that the technology of the RCS is quite viable. However, the RCS as tested also showed that the concept needs to be brought up to the level necessary to meet all the difficult environmental and operational requirements that would be encountered in a real waste site. This technology needs to be matured because its unique features offer great efficiency and cost savings to waste site characterization

Technology Transfer
Several DOE labs are involved or interested in furthering remote characterization. Its use with remote excavation and retrieval may enhance further funding and commercialization. The private sector, particularly those in the design of remote applications or hazardous remediation, should contact the developers for partnerships. The market for remote characterization is growing due to the high cost and safety aspects of intrusive characterization of waste sites and the growing number of sites that need this type of characterization such as areas with unexploded ordnance or unknown chemicals and chemical weapons. Therefore, the technology has application for Department of Defense and EPA Superfund sites. International markets also look promising with extensive cleanups in the newly independent countries and abandoned military testing areas.
Remote Characterization System at the INEL Cold Test Pit during 1993 BWID summer demonstration (93-488-2-23).

Remote Characterization System control station (93-488-5-17).
BWID DIG-FACE CHARACTERIZATION

This technology will be tested in FY 94

Principal Investigators
Nick E Josten INEL
Kevin M Croft INEL
Lyle G Roybal INEL
Peter Grabner Ecology International
Skip Snyder RUST Geotech Inc

Research Objective
Develop and test geophysical, chemical, radiological and environmental sensors to provide constant surveillance and screening for all categories of hazards at the dig face during excavation.

Technology Description
The dig face characterization project is an integrated demonstration of multiple sensors that can be used as part of a retrieval effort. The dig face characterization technology will allow continuous and continually improving monitoring and characterization of the site being remediated. The dig face characterization technique is integrated into the remediation process itself. As retrieval progresses, sensor data interpretation skills improve by comparing interpreted data images with the retrieved targets.

Geophysical, chemical, and radiological sensors are being deployed by a robotic system. The sensors scan over the surface being remediated. As waste retrieval proceeds, the sensors are continuously deployed to characterize the remaining waste. The remediation process proceeds in a stepwise manner in which the characterization data are interpreted online to support the retrieval process.

Waste Management/Remediation Need
The dig face characterization approach is applicable to any waste site undergoing retrieval. The technology is intended to be adaptable as required for a specific site.

Technology Attributes
The dig face technology reduces environmental health and safety risks during cleanup of buried waste sites. Real time data interpretation during the retrieval process allows for the incorporation of appropriate remediation equipment to maintain safety and environmental standards.

Planned Research

The major tasks that are planned for this research are:

<table>
<thead>
<tr>
<th>Task</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build prototype dielectric permittivity sensor and gamma spectrometer/chemical assay system</td>
<td>05/02/94</td>
</tr>
<tr>
<td>Test sensors along with the gantry crane and Schilling arm</td>
<td>08/30/94</td>
</tr>
<tr>
<td>Complete full scale demonstration of integrated system</td>
<td>09/30/95</td>
</tr>
</tbody>
</table>

The feasibility of the concept of characterization by deployment of multiple sensors during progressive soil removal has been demonstrated. Candidate sensors (geophysical, radiological, chemical) have been identified. Development of an automatic deployment capability and development of refined data interpretation techniques to support rapid target identifications will be powerful features of this technology.

Accomplishments
Three prototype sensors are being developed for dig face application: a gamma spectrometer, dielectric permittivity sensor, and focused electromagnetic induction sensor. Initial laboratory data have been obtained for the dielectric permittivity and gamma spectrometer sensors. Data indicate that both are feasible candidates for dig face application.

Field testing is in progress for automated deployment of dig face sensors using a robotic gantry crane system. This pilot scale testing uses a soil box to simulate the dig face and identify control system issues and needs.

Field testing of a prototype dig face characterization system has started at a test trench at the INF Cold Test Pit. The systems multiple sensors are deployed with a manual nonmetallic gantry designed and constructed to support obtaining dense data sets in a noninterfering environment. Data are being obtained for several.
commercial sensors (magnetometer, electromagnetic sensor, chemical sensor) deployed over simulated targets in multiple passes as soil layers are progressively removed. The data will be used to evaluate resolution capabilities of the sensors. It will also be used to develop interpretation schemes to support the real-time interpretation of targets needed for dig-face application.

**Technology Transfer**

The successful completion of demonstrations will result in a proven concept that is ready for technology transfer. Vendors supplying the base instrumentation and equipment for the sensors (Geonics Ltd.), those involved in waste cleanup and working with environmentally hazardous material (eCOLOgy International), robotic programs (Buried Waste Robotics Program), mining interests (Colorado School of Mines and USGS) have participated in the project. Individual sensors as well as combined systems (sensors and robotic arm) have commercial potential in manufacturing, mining, and waste cleanup operations. Implementation of the data display hardware and software will provide private industry and other DOE partners (Sandia National Laboratories, Grand Junction Project Office) with an easily adaptable system to specific site requirements. Disclosure of this research through professional journals and presentations at technical conferences will ensure transfer of this technology to a wider network of private-sector contractors that may be able to provide portions of the system, are performing waste site remediations, or have other remote-retrieval characterization needs.
NONINTRUSIVE SENSING OF ENVIRONMENTALLY IMPORTANT OBJECTS

This technology will be demonstrated in FY-94

Principal Investigators
Carl G. Schwenk, Skip Snyder, and Dave MacLean, RUST Geotech, Inc 
Louise Pellerin, U.S. Geological Survey 
Mary C. Pfeifer, INEL 
Ki Ha Lee, Lawrence Berkeley Laboratory

Research Objective
Develop and demonstrate the following technologies for the characterization of DOE buried waste sites: (a) site characterization and object location using a tensor magnetic gradiometer, (b) three-dimensional site characterization using broadband electromagnetics, and (c) electromagnetic methods for dig-face monitoring.

Technology Description
The tensor magnetic gradiometer (TMG) will nonintrusively acquire and reduce tensor magnetic data from a waste site in order to perform a site characterization. The system consists of an eight-element magnetometer/gradiometer and supporting software.

Broadband electromagnetics are advanced data reduction methods that must be applied to existing data sets from the TMG. The electromagnetic dig-face monitoring requires an optimal focused electromagnetic system using an array of high-sensitivity fluxgate magnetometers to estimate the five independent components of the gradient of the vector magnetic field.

Waste Management/Remediation Need
These advanced technologies will significantly improve the capability to perform nonintrusive site characterization for remediation of DOE buried waste sites.

Technology Attributes
These technologies are expected to offer significant improvements in sensitivity compared to existing instrumentation for nonintrusive characterization of buried waste.

Accomplishments
The basic TMG hardware has been constructed. Software to perform corrections, reduce data, and otherwise use the system is under development. To date, broadband electromagnetics data have been collected and analyzed using commercial software. An effort will be made to extract additional interpretive information using advanced techniques and developing new processing routines for specific applications. An optimal electromagnetic dig-face monitoring conductivity system has been designed and is undergoing hardware assembly. Software is under development to permit field testing in an apparatus that simulates the INEL dig face gantry.

Technology Transfer
The TMG testing and mobile deployment will result in a proven concept that is ready for technology transfer. Vendors supplying the base instrumentation and equipment for the TMG, firms involved in buried waste cleanup, companies interested in locating buried objects such as mining interests and oil companies, and Department of Defense contractors locating unexploded ordnance provide some of the markets and interest in this concept. In addition to DOE, the U.S. Navy and USGS have been participants in the project. The implementation and interaction of the data display hardware and software is of interest to both instrumentation manufacturers and software programmers. Disclosure of this research through professional journals and presentations at technical conferences will enhance transfer of this technology to a wider network of private-sector contractors, which may be able to manufacture or enhance portions of the system or find applications beyond buried object location.

Planned Research
The major tasks that are planned for this research are:
- Modify the TMG for mobile application and an advanced data interpretation using existing broadband electromagnetics data 03/31/94
- Field test electromagnetic methods for dig-face monitoring 06/30/94

28
Broadband electromagnetic demonstration at the INEL during the summer of 1992 (92-300-1-11).

Tensor magnetic gradiometer.

Broadband electromagnetic data of INEL Cold Test Pit.
FIELD DEMONSTRATION OF CHARACTERIZATION
TECHNOLOGIES

This technology will be demonstrated in FY-94

Principal Investigator
Steven Johnson, TechniScan (University of Utah)

Research Objective
Demonstrate imaging of buried objects in INEL soil with the three-dimensional scanner developed by TechniScan

Technology Description
The three-dimensional scanner, which was developed by TechniScan with funding through BWID, is an inverse scattering ground penetrating radar (GPR) system producing quantitative, distortionless images analogous to a computer automated tomography (CAT) system. It is intended to generate images of objects in INEL soil.

Waste Management/Remediation Need
This technology could be applied to the solution of characterizing buried waste at the INEL's Radioactive Waste Management Complex (RWMC) and other DOE sites. Specifically, it could contribute to identifying buried objects by shape, orientation, dielectric constant, and location.

Technology Attributes
The unique advantages of this technology compared to more conventional approaches for characterization of buried waste are:
(a) high spatial resolution
(b) self-focusing
(c) reverberation of free images
(d) quantitative images of dielectric constants

Accomplishments
In FY-93, TechniScan completed the development of a prototype three-dimensional scanner that will be ready to be tested in INEL soil in FY-94.

Planned Research
The major tasks that are planned for this research are:
Prepare scanner for testing at Cold Test Pit
Complete demonstration test with images being supplied as they become available
Evaluate the images and entire scanner concept

Technology Transfer
A successful demonstration of this technology will enable TechniScan to market the system throughout the DOE system and in the larger waste field, including Superfund buried waste characterization and remediation projects. Companies interested in locating buried objects, such as mining interests and oil companies, and Department of Defense contractors locating buried unexploded ordnance also might use the technology.
Tomographic microwave scanner.

Scale-model of ground penetrating radar scanner.
INEL NONINTRUSIVE CHARACTERIZATION STUDIES

This technology was initiated in FY-93 and will be completed in FY-94

Principal Investigators
David Parrish and W M Roggenhen, South Dakota School of Mines and Technology

Research Objective
Perform a multidiscipline assessment of existing underground radar surveys and mineralogy data at the INEL and publish a final report on the dielectric properties and attenuation as a function of radar wave frequency

Technology Description
A multidiscipline assessment of underground radar performance and the geophysical characteristics at the INEL's Radioactive Waste Management Complex (RWMC) will be performed to understand those issues that have, up until now, compromised this technology's performance at the INEL. Possible solutions could be found in such areas as unique data processing, optimum excitation wave shapes, excitation wave frequency content, excitation signal coupling, and signal processing.

Waste Management/Remediation Need
A viable underground radar survey of RWMC would provide critical data about the waste pits that would result in an estimate of the depth to the basalt at pit boundaries, depth to overburden/waste interface, and location of the original excavation boundaries.

Technology Attributes
This research could result in improvement of underground radar data at RWMC. Results of this research will be transferable to other sites, particularly those sites with high clay content soils.

Accomplishments
The assessment of existing underground radar performance in light of geophysical characteristics at RWMC is complete. Solutions to problems with the use of the technology at the INEL have been provided in two reports, Assessment of Existing Radar Surveys and Mineralogy at the INEL and Dielectric Properties and Attenuation as a Function of Radar Wave Frequency.

Planned Research
The major task that is planned for this research is
Review, approve, and publish final reports on existing radar surveys, mineralogy, and dielectric properties and attenuation 12/31/94

Technology Transfer
No hardware or software was developed for this effort. All information obtained through these studies is contained in these reports, which are excellent references for researchers when they develop the operational waste characterization systems for use at RWMC and elsewhere. The methodology relating underground radar and geophysical properties and possible solutions to lack of use have potential applications in transferring technology to other DOE and Superfund sites.
Ground penetrating radar survey conducted by South Dakota School of Mines and Technology (93-109-1-2).
**VERY EARLY-TIME ELECTROMAGNETIC (VETEM) SYSTEM**

This effort is being initiated in FY-94

**Principal Investigators**
Louise Pellerin and Victor F Labson,
U.S. Geological Survey
Mary C Pfeifer, INEL
University of California–Berkeley
University of Arizona
University of Utah
Colorado School of Mines
RUST Geotech, Inc
Lawrence Berkeley Laboratory
Oak Ridge National Laboratory
Sandia National Laboratories

**Research Objective**
Design a high resolution electromagnetic (EM) imaging system for shallow environmental problems (less than 10 meters) such as buried waste sites. Specifically, this system will be developed for use at waste sites where traditional EM equipment and interpretation techniques do not produce adequate results.

**Technology Description**
The very early-time electromagnetic (VETEM) system will collect and interpret data from the shallow subsurface. This instrument will operate in the region of the EM spectrum between low frequency EM induction and ground penetrating radar (GPR) frequencies. This region of operation allows the system to be used at sites where GPR has little success. The project not only will develop the instrumentation but also all other facets of the system. Physical and numerical models will be developed and used to determine instrument design criteria, and test processing and interpretation algorithms. New modeling, interpretation, and imaging algorithms must be developed to account for both diffusion and transmission effects. The instrumentation, modeling, and interpretation are being developed as a system so that the optimal package of hardware and software is achieved.

**Waste Management/Remediation Need**
This technology could be applied to the solution of characterizing buried waste at the INEL's Radioactive Waste Management Complex (RWMC) and other DOE sites. Specifically, it could contribute to identifying buried objects by shape, orientation, and location.

**Planned Research**
The major tasks that are planned for this research are:

- Develop one- and three-dimensional modeling codes
- Complete physical modeling to design an optimal system
- Fabricate a prototype transmitter loop
- Field test existing instrumentation and interpretation systems

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop modeling codes</td>
<td>05/31/94</td>
</tr>
<tr>
<td>Complete physical modeling</td>
<td>06/30/94</td>
</tr>
<tr>
<td>Fabricate transmitter loop</td>
<td>08/31/94</td>
</tr>
<tr>
<td>Field test instrumentation and interpretation systems</td>
<td>09/30/94</td>
</tr>
</tbody>
</table>

**Technology Attributes**
The resulting system, along with interpretation and imaging software, will enhance resolution of the shallow subsurface. Additionally, this system will operate at sites where the physical properties of the soils make high resolution GPR difficult.

Proposed research in FY-95 will focus on completing three-dimensional computer forward modeling and physical modeling, and continuing development and field testing of instrumentation with input from FY-94 research to optimize the system. The interpretation and imaging software will be developed and equipment will be completed and demonstrated in the outyears.

**Technology Transfer**
The opportunity exists for private-sector participation in the development stages of this effort. In addition, publications in technical journals and presentations at technical conferences will inform the private sector of the progress of the VETEM system. During the final stages of development, private companies will be solicited to commercially manufacture and use the system.
Vendors supplying the base instrumentation and equipment for EM firms involved in buried waste cleanup companies interested in locating buried objects such as mining interests and oil companies and Department of Defense contractors locating buried unexploded ordnance provide some of the markets and interest in this concept.

A prototype very early-time electromagnetic (VETEM) system developed by the USGS.
VIRTUAL ENVIRONMENT GENERATION OF BURIED WASTE

This technology is being initiated and a prototype system will be demonstrated in FY-94

Principal Investigators
Tom K Larson, INEL
Lance E Greenwade, INEL
Additional participants to be determined

Research Objective
Investigate the issues, requirements, and feasibility of developing a computer-generated virtual environment for buried waste sites

Technology Description
Simulation-based planning and design (SBPD) is the concept of applying computer simulation tools to the engineering process. A full-featured SBPD incorporates intelligent, integrated, automated, real-time control of the design process. Advanced visualization and computing, including virtual reality, multimedia techniques, and parallelized processing, must be effectively implemented into the design and analysis process. Using site characterization data, physics-based modeling allows virtual prototyping.

Waste Management/Remediation Need
The use of site characterization data to support advanced visualization and generation of virtual environments will play key support roles in SBPD systems. Ultimately, a full-featured SBPD system will be useful for site characterization analysis and design of actual remediation efforts and systems. An SBPD will also support worker training techniques for hazardous remediation.

Technology Attributes
Virtual environments and related visualization techniques have the potential to provide improved understanding of buried waste site characteristics. This improved understanding will assist in developing a remediation strategy. Improved imaging and manipulation techniques will advance remediation planning and operations.

Planned Research
The major tasks that are planned for this research are

<table>
<thead>
<tr>
<th>Development</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop rapid prototype environment</td>
<td>12/17/93</td>
</tr>
<tr>
<td>Complete requirements definition report</td>
<td>01/15/94</td>
</tr>
<tr>
<td>Develop Cold Test Pit prototype environment</td>
<td>09/30/94</td>
</tr>
</tbody>
</table>

Technology Transfer
The opportunity exists for private-sector involvement in the development of this technology. SBPD has applications for many engineering processes beyond buried waste remediation, such as various mining and manufacturing concerns. Research results will be published through professional journals and presented at technical conferences.

The available markets for SBPD and its application to an actual buried waste site (INEL Cold Test Pit) should encourage private-sector contractors to improve, manufacture, and use this system for both performing waste site remediations and other applications.
A computer-generated virtual environment depiction of objects in the INEL Cold Test Pit.
HIGH RESOLUTION IMAGING USING HOLOGRAPHIC IMPULSE RADAR ARRAY

This technology is being initiated in FY-94

Principal Investigators
H Dale Collins and
R P Gribble, Pacific Northwest Laboratory

Research Objective
Develop and demonstrate a field prototype and test a ground penetrating holographic (GPH) radar system using an air-coupled linear array that will generate real-time, three-dimensional images of shallow buried waste in low conductivity soils (i.e., dry sand)

Technology Description
The GPH system consists of a 1-meter linear array of tapered slot antennae, high-speed switching network, and relatively low power impulse source operating over a large frequency bandwidth (approximately 2.5 to 7 GHz). The bistatic array system is scanned above the surface, gathers the subsurface target data, and processes the three-dimensional holographic images. Image length is continuous as the vehicle travels across the terrain with the array mounted perpendicular to the scan direction.

Waste Management/Remediation Need
This technology could be applied to site characterization for buried waste in low conductivity soils (i.e., dry sand). High resolution images of buried targets (approximately 1 meter) in sand at the DOE Hanford Site have been generated with this technology. The objective of this GPH application will be directed toward imaging shallow buried waste at Hanford and the INEL.

Technology Attributes
This technology is expected to offer significant improvements with the three-dimensional volumetric imaging of buried targets using multifrequency simultaneous source/receiver holographic techniques. Lateral resolution is a factor of two greater than nonsynthetic aperture imaging techniques. The multifrequency holographic image is truly three-dimensional and provides an in-focus image at all depths.

Planned Research
The major tasks that are planned for this research are

- Design/fabricate the tapered slot antenna bistatic array 12/31/93
- Modify existing holographic array imaging software for demonstration 06/01/94
- Design and fabricate mounting fixture for array vehicle 07/30/94
- Complete demonstration at Pacific Northwest Laboratory 09/30/94
- Complete demonstration at INEL 09/30/95

Technology Transfer
The opportunity exists for private-sector involvement in the development of technology. GPH has applications beyond buried waste remediation. Various companies interested in locating other buried objects such as mining interests and oil companies, and Department of Defense contractors locating buried unexploded ordnance, provide some of the markets and interest in this concept. The implementation and interaction of the radar hardware and software with actual DOE waste sites is of interest to both instrumentation manufacturers and software programmers.

Research results will be published through professional journals and presented at technical conferences. This will enhance transfer of this technology to a wider network of private-sector contractors beyond remediation, mining, and instrument-manufacturing concerns. The available markets for GPH and its application to actual buried waste sites should encourage private-sector contractors to improve, manufacture, and use this system.
The figure on the left shows the actual size and shape of objects. Through the use of a ground penetrating holographic radar system, the images on the right were created.
This technology will be demonstrated in FY-94

**Principal Investigators**
Andrew J. Edwards, INEL
Bell Aerospace Textron, Inc

**Research Objective**
Evaluate and demonstrate the Bell Aerospace Textron Gravity Gradiometer Survey System (GGSS) at the INEL Cold Test Pit. Specifically, determine if the GGSS data from buried simulated waste targets have adequate signal strength and uniqueness to warrant investing in the research necessary to extract target details from GGSS data.

**Technology Description**
The GGSS was developed for the U.S. Navy's Trident Submarine Program. It was also developed as a spin-off for the U.S. Air Force to make gravity field measurements of onshore sites. Thus, it is an existing technology that can be transferred to DOE to assist with buried waste remediation efforts. The instrument detects gravity gradient, acceleration differences rather than absolute values. The approach implemented in this instrument results in an improvement in sensitivity over more conventional instruments by three orders of magnitude. This improvement is realizable by modulating the accelerometer signal and shifting the signal from direct current to 0.25 Hz (chopper stabilized). This results in a significant improvement in signal to noise ratios and, together with other techniques, allows direct measurement of the gravity gradient.

**Waste Management/Remediation Need**
This technology is being investigated for application to site characterization for buried waste. It may provide information to help locate original excavation boundaries, depth to the basalt at those boundaries, and depth to the overburden/waste interface.

**Technology Attributes**
This is an existing technology developed for the Department of Defense that could be transferred to DOE for waste remediation. It provides gravity gradients in all three axes, thus allowing sizing and positioning of gravity anomalies much more precisely than is possible with current DOE gravity measurement techniques. The measurements are noninvasive and may complement other technologies such as electromagnetics or radar.

**Planned Research**
The major tasks that are planned for this research are:

- Verify the GGSS to be functional, transport to INEL 03/31/94
- Perform demonstration test 04/30/94
- Complete evaluation 09/30/94

**Technology Transfer**
Collaboration with Bell Aerospace Textron, Inc., in applying this technology to a buried waste application will ensure that this technology will be commercially available. Technology development to determine locations of other buried objects such as tanks, pipes, and other objects might also be of commercial interest.
The Bell Aerospace Textron Gravity Gradiometer will be tested for site characterization of buried waste.
# IMAGING INFRARED INTERFEROMETER

This technology is being initiated in FY 94

## Principal Investigators
Glenn A. Moore, INEL Physical Sciences Inc

## Research Objective
Develop and test a variable wavelength infrared imaging system that can be used for standoff site characterization and remediation monitoring.

## Technology Description
Open path Fourier transform infrared (FTIR) spectrometers can monitor for volatile organic compounds (VOCs) and toxic gases. To provide real-time imaging, a standoff system will be developed using a real-time passive infrared imaging system with a Fabry Perot interferometer. The interferometer has mirror spacing that is comparable to the desired transmission wavelength such that continuous images of the field of view are produced with high sensitivity. A computer controls the mirror spacings, alignment, and processing of the infrared images. This approach will allow multispectral imaging of a 15 degree field of view over a 3.5 μm and 8.12 μm spectral range. The system will be enhanced specifically to monitor volatiles and offgas contaminants from a waste remediation site.

### Waste Management/Remediation Need
This technology will enable real-time wide area monitoring of a waste remediation site for volatile organic contaminants. This is particularly important for worker safety and keeping a remote operation clean enough to allow worker access for maintenance and repair.

### Technology Attributes
- **Major attributes of this technology**
  - The ability to identify point sources in a standoff mode
  - The degree of sensitivity to these contaminants
  - The ability to image and monitor a wide area in near real time

## Planned Research

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete draft system design specification</td>
<td>03/01/94</td>
</tr>
<tr>
<td>Construct prototype system</td>
<td>08/01/94</td>
</tr>
<tr>
<td>Complete field demonstration</td>
<td>08/15/95</td>
</tr>
</tbody>
</table>

## Technology Transfer
Physical Sciences, the private sector partner, is the primary avenue for technology transfer and commercialization. Superfund and Department of Defense sites may also have use for the technology. Nonwaste interests (e.g., mining and chemical processing) may be considered as partners for remote real-time infrared imaging.
The imaging infrared interferometer will be used to detect volatile organic contaminants (VOCs).

A Fabry-Perot infrared interferometer will be used for VOC imaging of a buried waste excavation pit.
Platforms for Electromagnetic and Magnetic Sensors

This research is being initiated in FY-94

Principal Investigators
Mary C. Pfeifer, INEL
Louise Pellerin, U.S. Geological Survey
Victor F. Labson, U.S. Geological Survey

Research Objective
Identify, develop, and evaluate various mobilizing platforms for electromagnetic and magnetic sensors used at buried waste sites

Technology Description
A variety of potential sensor mobilizing platforms already exist (from push carts to helicopters). A list of operational and sensor constraints is used to establish platform evaluation criteria. Potential platform candidates are then evaluated as to their impact on sensor performance and site survey requirements.

Waste Management/Remediation Need
The results of this study will provide DOE with a basis on which to evaluate platforms for buried waste sites and a means of selecting electromagnetic and magnetic platforms that are appropriate for a specific site. This technology could be applied to the solution of characterizing buried waste at the INEL’s Radioactive Waste Management Complex (RWMC) and other DOE sites. Specifically, it could contribute to identifying buried objects by shape, orientation, and location.

Technology Attributes
This study will provide DOE with an evaluation of electromagnetic and magnetic sensor platforms. Evaluation criteria will include cost of deployment, ease of use, availability, and suitability to buried waste problems. This will aid in determining which type of platform best fits the characterization system requirements of future buried waste projects.

Planned Research
The major tasks that are planned for this research are:

- Establish preliminary sensor platform evaluation criteria based on operational and sensor constraints
  - 11/30/93
- Perform an evaluation of these technologies against the criteria established in this study
  - 01/31/94
- Complete final report
  - 03/01/94

Technology Transfer
At the completion of this study, the final report will be distributed to the funding sources within the DOE Office of Technology Development so that it may be used to evaluate proposals received for consideration for funding in FY-95. Presentations at technical conferences will publicize the results to private-sector contractors.

The Department of Defense could use this technology for unexploded ordnance, hazardous chemical weapon retrieval, site characterization, and decontamination and decommissioning activities. The interaction of the sensor with the platform has robotic, ergonomic, and instrumentation ruggedness implications.
MAGNETIC AND ELECTROMAGNETIC GEOPHYSICAL SURVEYING

Demonstration of this technology was completed in FY-92

Principal Investigators
EBASCO Services, Inc
David E. Shropshire, INEL
Reva A. Hyde, INEL

Research Objective
Demonstrate how efficiently airborne magnetic and electromagnetic devices can map buried waste sites and characterize subsurface waste objects.

Technical Description
The airborne geophysical surveying system is a helicopter mounted set of standard mineral exploration sensors, including magnetic and electromagnetic sensor packages and ancillary electronic interrogation packages. The total magnetic field of the test areas is measured passively with a dual magnetic gradiometer system, which consists of two split-beam, optically pumped, cesium magnetometers, and two optically pumped helium magnetometers. This allows the vertical and horizontal gradient of the total magnetic field to be computed.

The electromagnetic active method uses three horizontal coplanar coil pairs and two vertical coaxial pairs. The positioning system allows accurate location of the helicopter to within 2 meters. Complete interpretation of the data will provide detailed information for characterizing buried materials and geologic information that can be used for hydrogeological modeling of the waste area. Data interpretation for each site is based on locating magnetic and electromagnetic anomalies, determining the amplitude of each anomaly above the total magnetic background reading, and correlating these anomalies with their most probable source.

Waste Management/Remediation Need
These surveying techniques could be used to provide the initial field screening of large DOE and industrial waste sites. Questionable areas can be quickly screened for possible burial sites and followup surveys with high resolution ground-based technologies.

Technology Attributes
Aerial surveillances enhance the speed of surveying waste sites nonintrusively and safely. Large areas of land can be screened quickly. Followup land-based surveys can then be dispatched to conduct detailed characterization efforts. The aerial data will reveal broad geological anomalies, and detailed surveys of waste sites can be referenced against the aerial data to identify anomalies specifically caused by buried waste.

Accomplishments
Airborne geophysical surveys were flown over the INEL's Naval Ordnance Disposal Area, Cold Test Pit, Subsurface Disposal Area, and SL-1 area with Ebasco sensors. The electromagnetic data produced broad anomalies, and buried waste areas could be defined and anomalies caused by buried objects could be differentiated from anomalies caused by geologic features. The ability to identify the details of individual sources from this aerial data was limited. The magnetic data were used successfully to delineate burial trenches and pits and have the potential for detecting ordnance.

Magnetic data were also used successfully in locating specific source areas within large burial areas. With additional data analysis and processing, magnetic data can be used to characterize ferrous objects.

Research Opportunities
It is recommended that research be performed to use the results of the aerial surveys to enhance data reduction of existing high resolution ground surveys inside of regions covered with aerial survey data.

Technology Transfer
This research demonstrated a commercialized technology and has been disseminated through professional journals and presentations at technical conferences. In addition to applications involving buried waste and ordnance, future collaboration and partnerships may involve underground tanks, pipes, and large objects, as well as augmenting mining data. Further definition of markets, combinations with other instrumentation, and computer algorithm developments would involve other contractors.
Helicopter-mounted standard mineral exploration sensors including magnetic and electromagnetic sensor packages (91-530-3-19).

Isometric display of INEL Cold Test Pit.
THERMAL INFRARED IMAGING SYSTEM

Demonstration of this technology was completed in FY-92

Principal Investigators
Martin Marietta Corporation
David E Shropshire, INEL
Reva A Hyde, INEL

Research Objective
Demonstrate an airborne infrared sensor method to detect and map ordnance and burned waste, and determine the feasibility of using automatic image-processing algorithms to detect objects of interest

Technology Description
Martin Marietta’s helicopter-mounted imaging system consisted of a gyro-stabilized infrared detector of the mercury-cadmium-telluride type. It featured four elements with a spectral range of 8-12 μm and closed cycle cooling, control electronics, IRIG time code generator, and video system. A ground station included an advanced thermographic image processor with the ability to process images in real time. Image-processing algorithms used morphological filters, edge-based detection approaches, multiple feature computations, linear classifiers, and other algorithms for object rejection, classification, and reporting.

Waste Management/Remediation Need
This technology could support the activity of characterizing DOE burned waste sites. It could help to locate specific areas of suspect burned waste that later can be surveyed with high resolution ground surveys.

Technology Attributes
Aerial surveillances provide a quicker way of surveying potential ordnance and waste sites. Larger tracks of land can be initially screened and areas of interest identified for high resolution ground surveys. Additionally, during the aerial surveillance, personnel will not be exposed to hazards.

Accomplishments
Surveys were flown over the Cold Test Pit, Subsurface Disposal Area, Naval Ordnance Disposal Area (NODA), and the SL-1 burial pit and trench at the INEL. Imaging was most successful at NODA. Results from this demonstration indicated the system has the potential to detect 6-in ordnance or shrapnel at depths of 1.2 feet below the surface. Ground surveys are necessary to validate identified anomalies.

Research Opportunities
Consideration should be given to operating multisensors on the aerial platform. Possible combinations might be electromagnetic, infrared, gamma, etc. More information would result from a single survey and data from the multisensors could be merged.

Technology Transfer
In addition to burned waste and ordnance, markets involving underground tanks, pipes, and large objects should provide incentive for collaboration and partnerships in further technology development. This research will be disseminated through professional journals and presentations at technical conferences. The basic technology exists in the private sector, but further definition of markets, combinations with other instrumentation, and computer algorithm developments would involve other contractors.
Helicopter-mounted infrared sensor imaging system (91-530-1-31).
NONINTRUSIVE CHARACTERIZATION AND SENSING OF BURIED OBJECTS

Demonstration of this technology will continue in FY'94

Principal Investigators
Pieter Hoekstra and Ray Lahti
Coleman Research Corporation

Research Objectives
Collect a geophysical data set of high spatial density with multiple sensors. Integrate the interpretations and develop imaging and display formats readily understood by environmental scientists and engineers.

Technology Description
Nonintrusive characterization is enhanced by collecting a high density of data using commercially available instruments and sensors [magnetic frequency domain electromagnetics (FDEM), time domain electromagnetics (TDEM), and ground penetrating radar (GPR)]. A high data density facilitates applying various filters and other processing methods that may enhance detection and resolution of site objectives.

The multiple survey instruments obtain survey data over the INEL Cold Test Pit (CTP) on magnetic field conductivity and GPR. The TDEM system is tested specifically for detecting shallow buried small metallic targets. Advanced techniques will be used to fuse the results from each of the individual data sets into a coherent interpretation of the targets at the pit. The fused result will be displayed as a three-dimensional representation of the INEL Cold Test Pit and compared with the actual targets in the CTP.

Waste Management/Remediation Need
This technology could be applied to the issue of site characterization for buried waste. It may provide information to help locate original excavation boundaries, depth to the basalt, at those boundaries, characteristics of the buried waste, and depth to the overburden/waste interface.

Planned Research
Phase II of the effort will continue with tests of GPR at the Idaho Chemical Processing Plant and Cold Test Pit. In addition, the following results are anticipated:

- Advance the data fusion methods 09/30/94
- Resolve the issue of poor magnetic sensor performance 09/30/94
- Develop advanced methods of displaying an overall interpretation of sensor data 09/30/94

- The variety of sensors that are used
- The advanced methods of fusing data from multiple survey instruments together
- The displaying of coherent results with three-dimensional plots of the survey site
- The use on a characterized buried waste site that simulates many DOE sites

Technology Attributes
This technology uses existing commercial instrumentation but is unique in several respects. Favorable results occurred only with the electromagnetic sensors. However, these results reinforce the importance of using multiple sensors in a site survey for characterization.

Technology Transfer
This research was conducted by the private sector (Coleman Research Corporation) through a Program Research Development Agreement. A paper is being prepared that will disclose the results of the research to the private sector at the Symposium on the Application of Geophysics to Engineering and Environmental Problems in 1994.
Operator collects survey data at INEL Cold Test Pit using nonintrusive sensing techniques.

Profile plots and contour maps obtained from TDEM metal detector.
WASTE CHARACTERIZATION

Point of Contact
Timothy J. Roney
EG&G Idaho, Inc.
RO. Box 1625
Idaho Falls, ID 83415-2209
Telephone: (208) 526-9712
E-Mail: TIY@INEL.GOV
RAPID TRANSURANIC MONITORING LABORATORY

Demonstration of this technology is continuing in FY-94

Principal Investigators
Charles V Mclsaac, INEL
Claude W Sill, INEL
Robert J Gehrke, INEL

Research Objective
Develop a field deployable Rapid Transuranic Monitoring Laboratory (RTML) that can continuously monitor airborne transuranic (TRU) concentration and rapidly analyze soil, smear, and air filter samples for TRU isotopes, and fission and activation products in a cost-effective manner

Technology Description
The unit can process over 100 samples per day of soils, filters, and smears in a field setting. The lower levels of detection vary depending on analysis system, the large area alpha ionization spectrometer can process 33 soil samples per day at 20 pCi/g (alpha). The U-L-Shell x-ray system can process 79 samples per day at 50 pCi/g (alpha) and 15 pCi/g (gamma). Simultaneously, the alpha CAMs can analyze air quality continuously at 1 DAC-hr. The unit can process over 100 samples per day of soils, filters, and smears in a field setting. The lower levels of detection vary depending on analysis system, the large area alpha ionization spectrometer can process 33 soil samples per day at 20 pCi/g (alpha). The U-L-Shell x-ray system can process 79 samples per day at 50 pCi/g (alpha) and 15 pCi/g (gamma). Simultaneously, the alpha CAMs can analyze air quality continuously at 1 DAC-hr.

Planned Research
The major tasks that are planned for this research are

Upgrade to incorporate screening capability for beta emitters and advanced screening technology for alpha emitters 08/01/94

Prepare documents with final specifications for technical journals 09/30/94

Technology Attributes
The RTML provides rapid onsite sample analysis at a lower cost per analysis than conventional methods. Samples can be processed in less than 1 hour for about $30 per sample using a technician-driven system. This compares to fixed laboratory results with radiochemists analyzing several samples per day at $200 to $300 per sample.

Waste Management/Remediation Need
The RTML is appropriate for any situation where there is a major problem with contamination of TRU that requires mitigation. The RTML can quickly evaluate situations and allow rapid remediation action to be performed that will prevent a situation from growing further out of control.

Accomplishments
The system was successfully demonstration tested at the Cold Test Pit at the INEL Radioactive Waste Management Complex during the summer of 1993.

Technology Transfer
The system is comprised of commercially available components. A commercial partner could begin manufacturing the integrated system. Disclosure of this research through professional journals and presentations at technical conferences will enhance transfer of this technology to private-sector contractors that may be performing waste site remediations. The INEL Environmental Restoration Program is planning to use the system as a screening tool during sitewide soil sampling in 1995.
Rapid Transuranic Monitoring Laboratory (RTML)
REAL-TIME MONITORING OF TRANSURANIC-CONTAMINATED DUST

This technology will be demonstrated in FY 94

Principal Investigators
Judy K Partin, INEL
James R Fincke, INEL
Charles V McIsaac, INEL

Research Objective
Develop and demonstrate a real-time, in situ instrument based on optical techniques for monitoring transuranic (TRU) contaminated dust. Incorporate alpha continuous air monitors (CAM) into the system to provide an improved radioactive assay capability for buried waste remediation sites.

Technology Description
A real-time dust monitor (RTDM) will monitor for TRU-contaminated dust based on laser-induced breakdown spectroscopy (LIBS) technology. The RTDM will be correlated with an alpha CAM system. An instrument will ultimately be developed for deployment to the field environment.

Waste Management/Remediation Need
The RTDM system is appropriate for any situation where there is a major problem with contamination of TRU that requires mitigation. The RTDM can quickly evaluate situations and allow rapid remediation action to be performed that will prevent a situation from growing further out of control.

Technology Attributes
The real-time monitoring aspects of this system will allow a potential contamination problem to be recognized as it develops rather than waiting until after the fact. The RTDM can be coupled with a CAM giving complementary information to CAM measurements for accurate alpha determination such as particle density. It also uses LIBS strength for detection of many hazardous heavy metals that have strong emission in the visible and ultraviolet regions.

Planned Research

<table>
<thead>
<tr>
<th>Task</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduct laboratory testing</td>
<td>12/01/93</td>
</tr>
<tr>
<td>Fabricate prototype</td>
<td>03/31/94</td>
</tr>
<tr>
<td>Plan glovebox test</td>
<td>03/31/94</td>
</tr>
<tr>
<td>Conduct INEL Test Reactor Area site installation and testing</td>
<td>06/30/94</td>
</tr>
</tbody>
</table>

Technology Transfer
The primary private customers for this technology are commercial nuclear reactors during decommissioning and decontamination phases of operation. However, the technology may also be applicable at any construction or decommissioning site where contaminated dust poses a potential health or environmental threat. Disclosure of this research through professional journals and presentations at technical conferences will enhance opportunities for transfer of this technology to private sector industry for commercialization. In addition, an opportunity presently exists for a government/industry partnership to promote the development and marketability of this technology.
Real-time transuranic contaminated dust monitor.
ASSAY OF CONTAMINATED SOIL FROM BURIED WASTE PITS

This technology is being initiated and demonstrated in FY-94

Principal Investigator
Timothy J. Roney, INEL

Research Objective
Develop a passive gamma-ray spectroscopy system to assay excavated and treated waste material for transuranic (TRU) content and investigate a neutron activation method to measure its hazardous material content

Technology Description
The system measurements will be made by four subsystems designed to optimize quantification and throughput. A real-time radiograph determines an average attenuation coefficient. A very high sensitivity, gross count gamma scanner determines gamma activity. A high-energy-resolution gamma ray spectroscopy system identifies and quantifies TRU. A neutron source for activation of hazardous metal enables detection and quantification. The detector for these activated metals is the gamma spectrometer.

Waste Management/Remediation Need
Retrieved waste will be assayed and packaged prior to shipment to an interim storage or treatment facility. Prior to treatment and at posttreatment prior to disposal, another assay will be performed. This system will be applied to both confirm and quantify the presence of TRU wastes and confirm that the clean stream output of treated wastes meets radiological requirements for disposal.

Technology Attributes
The principle attributes offered by this technology are improved accuracy, confidence in estimates, and assay of entire pretreated (sifted or ground) waste streams.

Planned Research

<table>
<thead>
<tr>
<th>The major tasks that are planned for this research are</th>
<th>02/01/94</th>
</tr>
</thead>
<tbody>
<tr>
<td>Begin technology demonstration</td>
<td>03/31/94</td>
</tr>
<tr>
<td>Demonstrate gamma ray spectroscopy system</td>
<td></td>
</tr>
<tr>
<td>Determine viability of active neutron for hazardous metals</td>
<td>06/30/94</td>
</tr>
</tbody>
</table>

Technology Transfer
This technology is planned for implementation by INEL Environmental Restoration. Opportunities exist for private-sector involvement in both development and commercialization of this technology. Hazardous metal applications include Superfund site and mining waste processing and emissions control. Other nuclear institutions that may aid in further research or be interested in testing systems particularly for their waste stream monitoring are nuclear power plants, DOE sites, isotopic production labs, and medical establishments.

Disclosure of this research through professional journals and presentations at technical conferences will enhance opportunities for transfer of this technology to private-sector industries.
Isometric view of passive gamma ray detectors and collimators with a sample box.
This technology was initiated in late FY-93 and will be demonstrated in FY-94.

Principal Investigators
Timothy J. Roney, INEL
Idaho State University

Research Objective
Enhance waste assay capability through improved individual measurement capability and integrating results together. Specific objectives include: (a) improved sensitivity and accuracy for gamma assay, active neutron, and thermal neutron capture measurements and (b) development of methods for integrating individual measurements for improved quantitative assays.

Technology Description
The Radiological and Hazardous Material Measurement System (RHMMS) consists of multiple measurement cells. A passive gamma spectrometer detects radiological decay of the gamma nuclides. Neutron interrogation is used for the detection of fissile material Pu-239 and U-235. Capture gamma is used for monitoring of hazardous material.

Planned Research
From FY-94 through FY-96, the RHMMS laboratory will be used to develop and demonstrate the integrated measurements approach of the RHMMS concept. The major tasks that are planned for this research are:

- Complete thermal neutron capture investigation: 01/01/94
- Develop computer model of calibration drum: 02/28/94
- Draft technology evaluation report: 08/31/94

Technology Attributes
The principle attributes offered by the RHMMS technology are improvements in accuracy and confidence of the systems estimates.

Accomplishments
A measurement laboratory dedicated to the RHMMS concept has been established at Idaho State University (ISU) and equipped with the necessary instrumentation. Computer modeling experiments have been performed. A Proton linear accelerator based neutron generator has been installed at the Particle Beam Laboratory at ISU.

Technology Transfer
Several expressions of interest from industry with regard to Cooperative Research and Development Agreements (CRADAs) are being evaluated. The completed system is planned for implementation by the INEL Waste Management Program. Disclosure of this research through professional journals and presentations at technical conferences will ensure transfer of this technology to private-sector contractors that may be performing waste site remediations.
Diagram of a linear-accelerator barrel monitoring cell.

- LINAC injector
- LINAC power supply
- Ion drift tube
- Lithium target
- Neutron D$_2$O moderator assembly
- Neutron measurement system pivot point
- 55 gallon barrel
- HPGe measurement system pivot point
- HPGe cryostat
- H$_4$ detectors (2)
- 3-30" detectors and 8-12" detectors per assembly
- Borated water shield tank

(b) Neutron measurement configuration
HIGH-SPEED DIGITAL RADIOGRAPHY AND COMPUTED TOMOGRAPHY OF WASTE DRUMS

This technology will be demonstrated in FY 94

**Principal Investigators**
Timothy J. Roney, INEL
Scientific Measurement Systems Inc

**Research Objective**
Demonstrate the capabilities and applications of a commercial scanner for high throughput digital radiography (DR) and transmission computed tomography (CT) of waste packages with emphasis on 55 gal waste disposal drums.

**Waste Management/Remediation Need**
DRCT will directly apply to the remediation of buried waste sites when the option of retrieve and treat is implemented. Retrieved intact containers and containers filled with retrieved wastes will be characterized and packaged prior to shipment to either an interim storage or treatment facility. Part of the assay process would be the use of DRCT to spatially characterize the package contents. Characterization may occur at several later stages including pretreatment, posttreatment and disposal.

**Technology Description**
A used, commercial DRCT scanner (circa 1987) has been acquired through government excess. The scanner uses x rays to measure density and nondestructively view the contents of waste drums. High throughput will be achieved by further enhancing the detection system to an area type detector versus a linear array. A high energy x-ray source is installed for interrogation of high density drums.

**Technology Attributes**
DRCT offers a unique capability to spatially characterize containers of waste as part of the assay process and provide quantitative information where only qualitative information has been available previously.

**Accomplishments**
The x-ray scanner is presently being refurbished and will be online at the INEL in FY 94.

**Planned Research**
The major tasks that are planned for this research are:

- Demonstrate upgraded DRCT's performance at vendor 12/31/93
- Ship DRCT to the INEL and install and verify operation 01/31/94
- Demonstrate DRCT performance at the INEL 07/31/94
- Develop high throughput for the DRCT system 09/30/94

**Technology Transfer**
Technology development and demonstration activities are being conducted with both government (INEL) and private sector (Scientific Measurement Systems Inc.) involvement. Industry involvement in the development and demonstration phases will enhance commercial applicability of this scanner.
IMPROVED TRANSURANIC WASTE ASSAY: CTEN

This technology was initiated in late FY-93

Principal Investigators
Kenneth Coop and Robert Fastep, Los Alamos National Laboratory

Research Objective
Develop a system to assay transuranic (TRU)/fissile contents of waste drums using both epithermal and thermal neutron interrogation to reduce inaccuracies caused by self shielding.

Technology Description
The widely used differential-dwellaway technique (DDT) method uses thermal neutrons to interrogate for fissile isotopes in waste drums. The resulting fast fission neutrons are detected in cadmium shielded helium detectors that are insensitive to the interrogating thermal flux.

The combined thermal/epithermal neutron (CTEN) method is similar to the DDT method, but interrogates the sample with both thermal and epithermal neutrons. This is achieved partly by the addition of 3He detectors, which have a faster response than 4He and can detect fast fission neutrons in the presence of the epithermal interrogating flux, and by a redesign of the moderating cavity so that thermalization occurs more slowly. Because epithermal neutrons are more penetrating in fissile material than thermal neutrons, the differential response can be analyzed to detect the occurrence of self-shielding by fissile material and measure the size of the effect. Self shielding occurs when lumps of fissile material are present, and can result in assay errors of several hundred percent. A fully operational CTEN device would be expected to perform all the functions of existing DDT/passive-active neutron devices with the added capability of identifying and assaying lumps of material.

Waste Management/Remediation Need
This technology will support the assay requirements of the retrieve and treat remediation option for buried waste. Specifically, it would apply to assay of the packages of retrieved waste prior to interim storage or treatment and posttreat ment assay of the final packaged waste

Planned Research
The major tasks that are planned for this research are

Complete Monte Carlo studies 01/31/94
Complete all design drawings 01/31/94
Complete fabrication, less final detector 06/30/94
Complete system software (first version) 07/31/94
Complete system and ready for test 08/31/94
Begin characterization and calibration 10/30/94

Technology Transfer
Though primary applications are in the waste field, use by fuel fabricators, international safeguard agencies, and Department of Defense special nuclear material monitoring may result in additional partners and provide incentive for joint testing, deployment, or markets. The research will be disclosed through professional journals and presentations at technical conferences to assist transfer of this technology to both private-sector contractors and other government agencies.
Schematic of a combined thermal/epithermal neutron (CTEN) instrument
ACTIVE AND PASSIVE COMPUTED TOMOGRAPHY
GAMMA ASSAY OF RADIOACTIVE WASTE

This technology was initiated in late FY-93

Principal Investigators
David C. Camp, Lawrence Livermore National Laboratory
Harry E. Martz, Jr., Lawrence Livermore National Laboratory
University of California-San Francisco
Bio-Imaging Research, Inc

Research Objective
Evaluate an active and passive computed tomography (A&P CT) system on low-level radioactive waste (LLW) and transuranic (TRU) waste contained in 55-gal drums

Technology Description
A&P CT uses a high purity germanium (HPGe) detector for nondestructive assay (NDA) of gamma-emitting nuclides in sludge, combustibles, and metal matrices within a 55-gal drum. Assay is necessary for determining radiological content for below regulatory concern (BRC) LLW, and TRU waste disposition of stored wastes, preassay and postassay of retrieved treated waste and residues, meeting shipping requirements, and meeting RCRA low-level mixed waste (LLMW) disposal regulations

Waste Management/Remediation Need
This technology will support the assay requirements of retrieved packaged waste prior to interim storage or treatment and posttreatment assay of the final packaged waste. Assay for pretreatment and posttreatment scenarios is possible

Technology Attributes
A I-HPGe-detector A&P CT drum scanner will
- Differentiate TRU from LLW, decreasing substantially shipments to the few LLW repositories that exist
- Enable DOE to meet potential more stringent transportation regulations for LLW and LLMW
- Give 10 to 100 times lower MDL for NDA drum waste assay than currently available segmented gamma spectrometry, 10 mg MDL for Pu 239 compared to 1000 mg
- Decrease assay time with the higher detection limits with multiple detector from 50 minutes to 30 minutes per drum

Planned Research
The major tasks that are planned for this research are
Scan and analyze drums of mock waste 12/31/93
Determine MDLs by optimizing performance parameters 02/28/94
Detailed A&P CT scans of first well-characterized drummed waste 06/30/94
DT&E scans of additional real waste drums using Waste Inspection Tomography (WIT) mobile trailer 03/31/95

Accomplishments
The A&P CT scanner has been developed to the state of system checkout and performance optimization

Technology Transfer
Technology transfer is under way with the private partner, Bio-Imaging Research, through development of WIT and the training, use, and data interpretation at DOE Sites. The University of California San Francisco Medical School has medical expertise that is helping with this development while seeking advanced applications to medical diagnostics.
Coupling multi-energy A&P CT data yields more accurate waste data characterization at numerous DOE sites will interest a variety of private environmental and waste assaying firms. Applications in the power industry and throughout the fuel cycle, particularly in fuel fabrication, are numerous. Safeguards monitoring and international use are also possibilities.

### 356-keV & 150-sec-ray-sum scan data

<table>
<thead>
<tr>
<th>ACT</th>
<th>Reference</th>
<th>PCT w/o ACT corr.</th>
<th>PCT w ACT corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Attenuation (pixels)" /></td>
<td><img src="image" alt="Counts/150 sec/2.54-cm-voxel" /></td>
<td><img src="image" alt="Summed counts" /></td>
<td></td>
</tr>
<tr>
<td>Summed counts (cts./time)</td>
<td>783,300</td>
<td>445,004</td>
<td>853,468</td>
</tr>
<tr>
<td>Difference from ref.</td>
<td>–</td>
<td>– 43%</td>
<td>+ 9%</td>
</tr>
</tbody>
</table>
ELECTROTHERMAL HOLLOW CATHODE DISCHARGE SPECTROMETRY

This technology will be demonstrated in FY-94

Principal Investigators
Stephan Weeks, Ames Laboratory
Martin Edelson, Ames Laboratory

Research Objective
Develop and test a prototype of an electrothermal hollow cathode discharge spectrometry system

Technology Description
Highly selective determinations of actinides and Resource Conservation and Recovery Act (RCRA) metals can be made for characterization and monitoring of environmental action levels by combining the diode laser-based absorption, fluorescence and optogalvanic methods used at Ames Laboratory with Furnace Atomization Nonthermal Excitation Spectrometric (FANES) systems. FANES is a versatile technique for elemental analysis and, when combined with diode laser-based optical spectrometric techniques, it can be used for isotopic analysis of actinides.

Waste Management/Remediation Need
This technology will complement the radiation measurement techniques used by the Rapid Transuranic Monitoring Laboratory to provide an onsite capability for quickly assessing radioactive or hazardous contamination problems associated with buried waste remediation.

Technology Attributes
This technology can provide highly sensitive qualitative measurements of samples of hazardous contamination. It can be mobilized in an onsite laboratory to provide rapid response times. The instrumentation being developed is sufficiently compact to be housed in a site-based laboratory. The technique requires minimal sample sizes (μg, μL, or μL/min) and is relatively rapid (minutes for an analysis). Minimum detectable quantities are in the picogram regime.

Planned Research
The major tasks that are planned for this research are:

- Begin field demonstration 04/30/94
- Develop FANES prototype instrument analytic methods 09/30/94
- Conduct field demonstration 10/31/94
- Install sampling and detector enhancements 09/30/95

Technology Transfer
Disclosure of this research through professional journals and presentations at technical conferences will ensure transfer of this technology to private-sector contractors that may be performing waste site remediations. This system could be used during retrieval actions to verify presence of hazardous materials and actinides in soils prior to return of the treated soils.
Instrumental block diagram of the electrothermal hollow cathode discharge spectrometry system
HAZARDOUS WASTE SEPARATION AT RWMC EXCAVATION SITES

This technology will be demonstrated in FY-94

Principal Investigator
Douglas W Akers, INEL

Research Objective
Develop a rapid chemical assay system (CAS) for hazardous chemicals in buried waste applications

Technology Description
The CAS is based on work performed for the last several years by the DOE Office of Arms Control (OAC). The CAS technology is currently in use by OAC and the U.S. Army for the characterization of various types of chemical weapons. The portable field use system can be carried by a single individual and used to assay a range of chemical weapons in the field. This technology will be adopted and modified for use with hazardous chemicals in DOE buried waste sites at the Radioactive Waste Management Complex (RWMC). The prompt gamma neutron activation analysis technique uses a small (5 \( \mu \)g) CF-252 source

Waste Management/Remediation Need
An immediate site-specific requirement for the use of this technology is the presence of large amounts (200,000 gal) of chlorinated hydrocarbons present in Rocky Flats sludge. This mixed waste should be separated before substantial mixing with other debris at the excavation site occurs. Its primary use will be to analyze closed containers or material deposits, which have no volatile constituents and are not susceptible to gas chromatography analysis. Use of this technology may substantially reduce the volumes of mixed hazardous wastes that need to be treated

Technology Attributes
This nonintrusive technique will identify hazardous content of waste containers and, if applied at retrieval or treatment to sort waste, could make the remediation process much more efficient

Planned Research
The major tasks that are planned for this research are

Assess the effects of elemental interferences on the hazardous chemicals for which analysis is being performed 03/31/94

Train staff at RWMC in the use of CAS and provide technical support as required 06/30/94

Perform an assessment of the potential applications to wastes at other laboratories in the DOE complex 09/30/94

Technology Transfer
This task will assist in determining applications for this technology in the waste management/environmental restoration arena. The technology will also be implemented by INEL RWMC staff in 1994. Disclosure of this research through professional journals and presentations at technical conferences will enhance opportunities for transfer of this technology to private-sector industry for commercialization
The chemical assay system (CAS) being used to assay chemical weapons in the field (92-387-10-18).
Point of Contact
Brad E. Griebenow
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415-3710
Telephone: (208) 526-0501
E-Mail: BEG @ INEL.GOV
CONTAMINATION CONTROL UNIT (CCU)

Demonstration of this technology was completed in FY-93

Principal Investigators
Guy G. Loomis, INEL
David N. Thompson, INEL

Research Objective
Design, construct, and test an easily deployed mobile unit to efficiently and inexpensively suppress contaminated dust during excavation of buried waste

Technology Description
The Contamination Control Unit (CCU) was specifically developed to suppress and fix contamination, and to inhibit its spread during retrieval operations of buried waste that are normally quite dusty. The CCU is capable of dispensing soil fixatives, dust suppression agents, and misted water, and uses a vacuum system to control contamination spread. The CCU is a 9 ft x 26 ft trailer. The vacuum, a nuclear grade system with a HEPA filter and a critically safe 55-gal waste container, can pull 1-in debris through 100 ft of hose.

The dust-suppressing system applies a water mist, soil fixant, and dust suppressant. The water misting system, Dryfog (manufactured by Sonics, Inc.), uses compressed air to force demineralized water through four nozzles. The nozzles discharge a mist curtain that captures and removes aerosolized soil. The concentrated soil fixant, Foamer (manufactured by 3M Inc.), is combined with a stabilizer and water pumped from a trailer-mounted, 325-gal tank. The stabilizer and concentrate are stored in 5-gal cans near the nozzle and are delivered by suction to the nozzle. The dust suppressant, Flambinder (calcium lignosulfate, manufactured by Flambeau Corporation), is commonly used on U.S. Forest Service roads to suppress dust. This product is mixed with water stored in a 325-gal tank, and pumped to a nozzle via a hose and reel system. Flambinder cures in a few hours and can withstand traffic of hundreds of vehicles without reaplication.

Waste Management/Remediation Need
The technology demonstrated with the CCU fulfills the need of suppressing contamination spread during buried waste retrieval operations.

Technology Attributes
The CCU provides a reliable, easy-to-use, easily deployable system to control dust. Use of the CCU improves personnel safety and reduces the risk of contamination spread by airborne dust. All the dust control products are nonhazardous and can be disposed of in sanitary landfills. In a field deployable setting, the unit is capable of fixing 500 ft²/min with a total encapsulated (3M Foamer), or applying 1,000 ft²/15 min of dust suppressant (Flambinder) while simultaneously providing 2 gpm mist from four misting nozzles. The vacuum system can be operated continuously during the spray operation. In an emergency response situation, the system is capable of spraying dust suppressant at a rate of 1,000 ft²/3 min.

Accomplishments
The CCU was designed in FY-92 and assembled and performance tested in FY-93. Currently, it is being used by the Environmental Restoration Program at Hanford for a retrieval treatability study. The unit was also used by the INEL Environmental Restoration Program during a capping action at Experimental Breeder Reactor 1 in which Wendon dust suppressant was sprayed on a slightly contaminated soil site of about 15 acres. Fernald has expressed an interest in using the unit in the FY-94/95 time frame to supply contamination control during actual retrieval actions. The unit is completely developed and ready for ER use throughout the DOE complex.

Research Opportunities
Consideration is being given to remotizing this kind of technology. The remote control technology of the Remote Excavation System (RES) or dig-face characterization could provide the remote operating capability. However, a feedback scheme is necessary to provide accurate real-time information on the dust level and contamination level in the region where the system is trying to suppress it.

Technology Transfer
The system is being used throughout the DOE complex. Disclosure of this research through professional journals and presentations at technical conferences will ensure transfer of this technology to private sector contractors that may be performing waste site remediations.
Applying 3M foam to an incline at a retrieval site during the 1993 BWID summer demonstration [93-507-2-25].

Contamination Control Unit at retrieval site.
FIXATION OF SOIL SURFACE CONTAMINATION USING NATURAL POLYSACCHARIDES

Demonstration of this technology was completed in FY 93

Principal Investigator
Mike R. Sackschewsky, Westinghouse Hanford Company

Research Objective
Demonstrate the use of inexpensive, environmentally acceptable, dust suppression materials that will not adversely impact subsequent soil treatment processes

Technology Description
Natural polysaccharides from sugar beet and potato starch are readily available as byproducts from agricultural processing. Polysaccharides are mixed as either aqueous suspensions or solutions and sprayed on the area as needed to control dust. Soil dust is suppressed either by forming a surface crust or agglomerating soil particles. These products fix soil contaminants in a soluble matrix that can be easily broken down during soil treatment processes. Product effectiveness depends on soil type, application concentration, and angle of soil. Costs are lower than synthetic chemical but are not as resistant to weathering.

Waste Management/Remediation Need
These products can be easily applied during remediation operations to suppress dust generation and contamination spread. DOE, EPA, and Department of Defense sites that need some type of retrieval are all candidates for this type of dust control. Their application might also prevent nonsoil dusting in industrial processes. Reducing dust generation on large disturbed areas where synthetic chemicals are not permitted is one area of immediate application.

Technology Attributes
Natural polysaccharides are:
- Inexpensive and easily applied products
- An improvement in worker safety in contaminated excavation environments by reducing dust generation and spread of airborne contaminants
- Nontoxic and biodegradable
- Readily removed from sandy soil
- Custom formulated and applied for dust suppression in a variety of soil types and conditions
- Ideal for short term applications where environmental breakdown is needed

Accomplishments
Laboratory analyses, wind tunnel evaluations, and a large-scale demonstration at the INEL Cold Test Pit of natural polysaccharides were conducted. Laboratory analyses indicated polysaccharides could be removed from most soil and residues probably would have no effect on soil-washing systems.

Wind tunnel evaluations indicated potato starch was useful for steep dig-face stabilization and was preferable to the synthetic types. The liquid sugar-beet product with additives (XDCA) decreased contamination by at least 95% over untreated Hanford soil. Potato starch or concentrated XDCA gave some protection to Idaho soil up to 14% over untreated soil. A fermented potato waste (FPW) gave intermediate results for all soil types. Long term applications favor synthetic products, although removal of any products from silty soil is difficult.

Large-scale demonstration of XDCA, FPW, and potato starch to an excavated areas at both Hanford and Idaho allowed application rates to be determined and verified findings of the laboratory tests. The potato starch costs about 50¢/lb, or 5¢/yd² when applied to soil surface at field effective rates. A nonpregelled product will separate in the tank and tends to clog the spray nozzle.

XDCA costs about 50¢/gal for the concentrate, or about 16¢/yd² when applied on Idaho or Hanford soil surfaces. It appeared to be longer lasting than the other products though not as long as synthetics. FPW is not yet commercially sold as it is still being developed by Pacific Northwest Laboratory. The performance in the field was similar to laboratory tests. Potato starch worked best on Idaho soil and XDCA on Hanford soil, with FPW in between and considered to be the best broad spectrum product.

Technology Transfer
The markets for commercial products have been established and all but one product are commercially available. Proof of successful application on specific DOE soils during typical retrieval operations will enhance viability of polysaccharide products as well as biodegradation and short-term low residue requirements.
Applying natural polysaccharides to an incline at a retrieval site during the 1993 BWID summer demonstration (93 499 1 23)
ELECTROSTATIC CURTAIN

Demonstration of this technology was completed in FY-93

Principal Investigator
Leroy C. Meyer, INEL

Research Objective
Develop and evaluate an engineering-scale electrostatic curtain to control contaminated dust dispersal during waste excavation and retrieval

Technology Description
Electrostatic curtains can provide in-depth contamination control during transuranic (TRU) waste-handling operations. As the TRU material radioactively decays, the particles become electrostatically charged. The electrostatic curtain uses grounded conducting plates to form the walls of an inner containment structure to capture the charged contaminated dust particles. The grounded conducting plates also are used in a ventilation system upstream from a HEPA filter to neutralize charged dust particles entrained in an air stream drawn from within an enclosure. A double enclosure with a ventilation system was used for the experiments.

Waste Management/Remediation Need
The electrostatic curtain could be part of an overall electrostatic enclosure that is used as an in-depth contamination control strategy for a TRU waste retrieval/treatment operation

Technology Attributes
The electrostatic curtain technology will control the spread of TRU contamination during waste retrieval/treatment operations. This technology will minimize dispersal of electrostatically charged contaminated dust during excavation and retrieval. This maintains a safer work environment in contaminated environments. Removal efficiencies as high as 99% have been obtained in ventilation systems.

Accomplishments
The electrostatic curtain project has progressed from proof-of-concept experiments in a glovebox to engineering-scale demonstrations in FY-93. Three different devices were investigated in the experiments: a 3M electret filter, an electric field test fixture, and parallel arrangements of metal plates. The electret materials were found to be 99% effective, the parallel plates were 20-50% effective, and the electric fixture was least effective.

Technology Transfer
Full-scale demonstration of this technology has not been completed. An opportunity exists for private-sector industry interested in further development and commercialization of the electrostatic curtain. Full-scale demonstration may be conducted at the INEL in 1995.
Engineering-scale electrostatic curtain enclosure walls with ventilation system (93-607-1-9).
OVERBURDEN REMOVAL

Demonstration of this technology was completed in FY-93

Principal Investigators
Sonsub, Inc
Phillip M Rice, INEL

Research Objective
Demonstrate that discrete thicknesses of overburden soil can be removed with precision and that fugitive dust can be controlled during excavation

Technology Description
The overburden removal system is a Caterpillar EL300B excavator fitted with an innovative end effector. The end effector is specially designed to remove incremental layers of soil from the area of excavation. Two vacuum ports were installed on the end effector's front edge and two on the rear to remove much of the dust generated while cutting. The vacuumed dust is routed through hoses into a knockdown box. A laser referencing system provides a constant grade reference by transmitting radio signals to a display in the operator's compartment to indicate if the end effector is above, below, or on grade.

Waste Management/Remediation Need
This technology can fulfill the need of overburden removal as part of the retrieval of DOE buried waste. This system can be used at any site requiring the precise removal of incremental layers of soil (either contaminated or clean) without dust generation or contamination spread.

Technology Attributes
By using this system, one can accurately skim layers of 'clean' overburden soil from a waste site to minimize the amount of waste-soil that needs to be treated. The system can also be used to precisely excavate surficial contamination to minimize the amount of waste soil that needs to be treated. The vacuum system reduces potential contamination risks to the operators by reducing the generation of dust. The system can remove clean or contaminated soil in controllable layers using 3-in, 4-in, or 6-in cuts with an accuracy of ±1 in. The system can remove 6 ft of soil over 1 acre in ten 8-hour days.

Accomplishments
A demonstration was conducted at the INEL Cold Test Pit. The test area was leveled and spiked with erbium, a rare earth tracer, to detect dust spread. Air filters were placed around the test area and on the excavator to monitor dust generated during operations. The equipment removed the layers of soil with extreme precision and accuracy. For the demonstration, 3-, 4-, and 6-in by 3-ft layers of soil were removed from a 40 x 155-ft test area with an average production rate of 11.6 yd³/hr. The dust collection system functioned efficiently, the air monitor analysis results proved that the soil could be excavated without spreading contamination. An experienced, proficient operator is essential.

Research Opportunities
Consideration should be given to coupling the proven remote control technology demonstrated by the Remote Excavation System (RES) with this class of excavator for overburden removal.

Technology Transfer
Through collaboration with a private-sector partner, technology is already developed in the commercial sector. Publication of these results in technical journals and presentations at conferences will increase the interest of end users for additional applications.
Overburden removal demonstration at INEL Cold Test Pit during 1993 BWID summer demonstration (93-588-1-26)
REMOTE EXCAVATION SYSTEM (RES)

In FY-94 this technology will be applied to a specific waste site

Principal Investigators
Barry L. Burks, Stephen Killough, and David Thompson, Oak Ridge National Laboratory
US Army
Bruce M. Wilding, INEL
Reva A. Hyde, INEL
Stephanie Walker, INEL

Research Objective
During FY-93, demonstrate and evaluate a system to remotely excavate radioactive waste, unexploded ordnance, and other hazardous wastes. During FY-94, test and demonstrate the use of remotely operated excavation technology for applicability to a specific class of buried waste remediation

Technology Description
A previously developed remote excavation system (RES) will be used to excavate the Hill Cut Test Facility at Oak Ridge National Laboratory (ORNL). During the field tests, the vehicle will be equipped with dosimeters to assess the operator exposure risks during overburden removal and cask handling. A grappling end effector must be developed and integrated with the existing RES and control station. A standard military vehicle, the Small Emplacement Excavator, was modified by ORNL for remote operation and computer-assisted control. The excavator boasts automated dig and dump functions, multiple video cameras, joint encoders, and other sensor feedback. Video and control data are transmitted to the control station via radio frequency links or fiber optics. A joystick controller and a graphical computer interface were developed to provide a remote control station that is easy to use and does not require line-of-sight operation.

The RES will be used to remove the overburden and to manipulate the disposal casks so rigging can be attached. The majority of the casks will be transported to the Interim Waste Management Facility (IW/WM) staging area where they will be placed in the standard IW/WM concrete casks prior to disposal in tumulus units. The approach will provide a precommercialization field test of remote excavation technology that could have widespread application to buried waste site remediation. Dosimetry measurements during excavation will provide worker exposure data for future risk analyses. The grappling end effector and controller will integrate manipulation technology with heavy equipment technology.

Waste Management/Remediation Need
The RES can be used for remote excavation of radioactive and hazardous sites and for retrieval of unexploded ordnance. The controls technology developed for this project was implemented in a modular fashion that permits rapid transfer of the technology to other excavator platforms. High surface dose rate waste, likely to be encountered in many buried waste sites, will require remote techniques for excavation. At other sites, remote retrieval may be desired due to other safety concerns, such as explosion and fire potential. The concrete casks in the Hill Cut Test Facility provide an attractive test because the potential for contamination spread is minimal.

Technology Attributes
With the RES, materials can be excavated and retrieved in a hazardous environment without endangering operator personnel. The RES is designed for relatively small excavations. Remote operation of the system demonstrated a retrieval rate of approximately 2.4 ft³/min, while manual operation under test conditions achieved rates 50% higher.
Accomplishments
The RES was demonstrated at the INEL Cold Test Pit and the U.S. Army Redstone Arsenal to evaluate the feasibility of excavating buried waste and unexploded ordnance with a remotely operated vehicle. At each of these demonstrations, the relative performance benefits of teleoperation and telerobotic excavation were evaluated and documented. The demonstration showed that the system can be operated remotely to effectively excavate buried waste. The advanced control technology and computer-assisted operations made excavation relatively easy for both inexperienced and experienced operators.

Research Opportunities
Research will be conducted on (a) radiation exposure risks during manual retrieval operations and exposure reduction using telerobotic excavation, (b) development and fabrication of a custom end effector, including a quick disconnect mechanism, and (c) development of an operator interface and controls algorithms for the grappling end effector.

Technology Transfer
Disclosure of this research through professional journals and presentations at technical conferences will ensure transfer of this technology to private-sector contractors that may be performing waste site remediations. Many companies have expressed interest in the control technology and the operator interface technology developed by ORNL, and several are pursuing Cooperative Research and Development Agreement (CRADA) scope negotiations. Mechanisms will be sought to transfer the technology to interested parties.
RETRIEVAL DEMONSTRATION

Demonstration of this technology was completed in FY-93

**Principal Investigators**
Brian D. McFeeters, Caterpillar, Inc
Martin Marietta Aero & Naval Systems
David J. Valentich, INEL

**Research Objective**
Demonstrate the effectiveness of full-scale commercially available excavation equipment and end effectors for the retrieval of simulated buried waste forms typical of DOE sites.

**Technology Description**
Commercially available equipment was manually operated and then evaluated for suitability for buried waste retrieval and remotization capability. The equipment included a 325L excavator with Balderson thumb end effector, 935C track loader with multipurpose bucket, EL200B excavator with front shovel, IT28B integrated tool earner with grip and grab end effector, and 235B excavator outfitted with a pair of Allied Gator shears.

**Waste Management/Remediation Need**
Optimization of retrieval equipment is essential when working in hazardous environments. Coupling this type of equipment with the type of remote operation technology that was demonstrated on the Remote Excavation System (RES) will satisfy the required capabilities of handling heterogeneous waste forms at DOE waste sites.

**Technology Attributes**
Commercially available equipment can be readily obtained to support the different requirements of retrieval operations. All of the equipment has been used by industry and proven reliable. The use of this equipment can improve throughput rates. The average production (retrieval) rate of this equipment was determined to be 400 yd³/day (8-hour day). This rate far exceeded the target goal of 80 yd³/day. The 325L excavator with Balderson thumb proved to be the most versatile, operating effectively both abovegrade and belowgrade. It was capable of handling 1 yd³ loads of heterogeneous waste with no spillage and could selectively grab small 1-in-diameter cables as well as handle large objects such as a 6-ft metal cube.

**Accomplishments**
After a competitive bidding and review cycle, a subcontract was awarded to Caterpillar, Inc., for a full-scale retrieval demonstration, which was conducted in June 1993 at the Caterpillar Edwards Training Center near Peoria, Illinois. The demonstration was performed at a simulated waste pit constructed on this site. The simulated waste pit (overall size 70 x 32 x 13 ft) was comprised of three separate cells, a stacked drums and boxes cell (35 x 32 x 13 ft) an earth separation berm (10 x 32 x 13 ft), and a random dumped drums and boxes cell (25 x 32 x 13 ft). Excavation of the pit occurred in four passes, each 8 ft wide, moving lengthwise along the pit. The first two passes were excavated from the belowgrade position and the last two from abovegrade. Various equipment was tested during the demonstration. The successful demonstration proved that standard excavation equipment can accomplish the retrieval of buried waste. Valuable information also was obtained concerning the remotization of this equipment.

**Research Opportunities**
Coupling the remote control technology with this class of excavators is being conducted in FY-94.

**Technology Transfer**
This class of technology is already in the commercial sector. The remotization of this equipment offers opportunities for collaborative efforts. The results will be presented in technical journals and at conferences.

84
Full-scale retrieval demonstration at Caterpillar Cold Test Pit site in Illinois.

Close-up view of retrieval demonstration at Caterpillar Cold Test Pit.
FULL-SCALE REMOTE RETRIEVAL

This technology is being initiated and will be demonstrated in FY-94

Principal Investigators
John K. Rawlins, INEL
Industry participants to be determined

Research Objective
Develop and deploy a full-scale, remotely operated excavator. Production rates of the remotely operated vehicle will be compared to production rates of manual retrieval operations. Analysis will be provided of the final system that may improve the efficiency of the remote operations.

Technology Description
A 60,000-lb-class, hydraulically driven excavator with a 1 yd³ bucket and thumb will be modified to allow teleoperation from a remote location. The operator will be isolated from the excavator so that direct visual and audible information is denied. The control system will provide the operator with control of the excavator functions, readout of required excavator information, and visual and audible information to perform the retrieval tasks. Both two-dimensional and three-dimensional camera systems will be used to allow studies on visual requirements.

A simulated buried waste pit will be constructed with both a random dumped drum and box area, which will also contain large objects, and a stacked drum and box area. The remotely operated excavator will be used to retrieve the simulated buried waste to determine baseline production rates. The retrieved waste will be placed in a transport container and a forklift will be used to move the container to a separate location. In addition to retrieval, experiments designed to determine the efficiency of remote operation and machine dexterity will be carried out in the field. These experiments will include trying different shovel and thumb positions, grasping small objects remotely, grasping and removing cable selectively, handling large and difficult-to-maneuver objects, grasping and handling intact containers so as not to damage or breach the container, and trying different placement methods through the funnel into the transport box.

Waste Management/Remediation Need
Based on safety analysis done in the past, the retrieval of buried waste will be required to be performed remotely. Radioactive contamination is a concern, but larger concerns identified in the safety analysis include explosion and fire potentials. The planned activities will prove the effectiveness of full-scale, remote-operation technology.

Planned Research
Research will be conducted on (a) the development of a control system to be applied to a 60,000-lb-class excavator, (b) vision systems that could be mounted on the excavator to simplify remote operations, and (c) additional operator aids that may simplify remote operations.

The major tasks that are planned for this research are:
- Complete remotizing excavation
- Complete field remote demonstration
- Publish technology evaluation report

<table>
<thead>
<tr>
<th>Task</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete remotizing excavation</td>
<td>06/15/94</td>
</tr>
<tr>
<td>Complete field remote demonstration</td>
<td>08/01/94</td>
</tr>
<tr>
<td>Publish technology evaluation report</td>
<td>09/30/94</td>
</tr>
</tbody>
</table>

Technology Transfer
The technology development performed as part of this activity will be done by industry. Cooperative Research and Development Agreements (CRADAs) may be developed with the industrial partner to transfer technology developed by Oak Ridge National Laboratory as part of the Remote Excavation System.
Conceptual drawing of a telerobotic retrieval demonstration using a 60,000-lb-class, remotely operated excavator.
THREE-DIMENSIONAL SIMULATION

This technology will be demonstrated in FY-94

**Principal Investigator**
Robert King, Colorado School of Mines

**Research Objective**
Modify existing commercially available software packages to provide a graphical Three-Dimensional Dynamic Simulation Tool (3DDST) for BWID systems analysis

**Technology Description**
The graphical 3DDST will illustrate the BWID characterization/retrieval/ex situ treatment configuration option and visually define the relative merits of proposed technical development activities. The flexible graphical tool will compare numerous systems that can be built with a myriad of alternative retrieval technologies. It will be a modification of existing software packages and able to add and subtract objects, layouts, and equipment to form three-dimensional images of several configuration options. It will be able to display different DOE sites and retrieval environments.

**Waste Management/Remediation Need**
ER/WM needs to produce detailed plans for retrieving buried waste. BWID supports the development and demonstration of technologies that can be integrated together with baseline technologies to form a comprehensive remediation system for ER/WM. The 3DDST will assist both of these needs.

**Technology Attributes**
This graphical tool:
- Visually defines the relative merits of proposed technical development activities of the BWID characterization/retrieval/ex situ treatment configuration option
- Identifies crosscutting technologies, comparing existing and emerging technologies and technology gaps, and illustrating how these components fit into the overall system
- Provides communication for presenting possible system scenarios to a diverse group in the BWID alliance of DOE laboratories, Federal agencies, and universities

**Planned Research**
Cost-effective hardware and software packages will be selected for the 3DDST. It will be programmed to demonstrate system capabilities for system analysis. Based on feedback, the 3DDST will be modified and then applied to selected configuration options.

The major tasks that are planned for this research are:

- Demonstrate the capabilities of 3DDST 05/02/94
- Modify and conduct final demonstration 09/30/94

**Technology Transfer**
Commercial participants for software and hardware will be identified and obtained in the first phase of this effort. It is envisioned that the demonstrated prototype system will foster the optimization of this approach. This action will ensure the availability of this system to the ER/WM elements at all applicable DOE sites as well as other complex hazardous waste sites.
COOPERATIVE TELEROBOTIC RETRIEVAL

This technology will be demonstrated in FY 94

Principal Investigators
Kevin M. Croft, INEL
Scott M. Allen, INEL
Industry participants to be determined

Research Objective
Develop the capability to perform selective, or surgical, retrieval at a buried waste site. Two robotic manipulators will be installed on a delivery system for use at the site. The manipulators will be used in tandem activities to selectively remove debris from around the article of interest and to retrieve that article.

Technology Description
A study will determine the type of delivery system required to transport dual manipulation capability to the dig-face. It is anticipated that ultimately, the delivery system will be used not only to transport the manipulators, but also to deploy a contamination control unit, dig-face characterization equipment, sizing equipment, and other equipment required at the dig-face.

A remotely operated vacuum system will remove soil and debris from around the object of interest. End effectors to be used with the vacuum system will be designed to break up hard soil, carefully clean around buried objects, and ensure that large sheets of plastic and other objects do not plug the system. The vacuumed debris will be placed in a transport container for subsequent removal and treatment. A control system will be developed to control the required number of motions. These motions will include the control of the delivery system, all degrees of freedom on both manipulators and the vacuum system.

Planned Research
The major tasks that are planned for this research are:

- Requirements for a delivery system that could be deployed at a buried waste pit dig face and capabilities of currently available delivery systems 03/01/94
- A vacuum system and related end effectors to remove soil and debris from around a buried object 06/01/94
- The expansion of a control system to control the numerous axes of motion involved in surgical retrieval operations 06/01/94
- The control of dual, cooperative, manipulation activities 09/30/94

Technology Attributes
This research will:
- Identify a delivery system to transport equipment, such as robotic manipulators, to the buried waste pit site.
- Design and fabricate a remotely operated vacuum system to remove soil and debris from around objects to be surgically removed.
- Develop a control system capable of controlling the required axes of motion.
- Develop the capability to control two robotic manipulators used in cooperative activities.

Technology Transfer
Industry participation is anticipated in the development of a delivery system to be used in this project. Advances made in the expansion of a control system will be transferred to the control system manufacturer partnered in these activities. Capabilities developed at Oak Ridge National Laboratory in the area of coordinated, dual manipulation will be used in the current development efforts.
Conceptual drawing of a cooperative telerobotic retrieval system.
WASTE CONVEYANCE AND INNOVATIVE END EFFECTOR

This technology will be demonstrated in FY-94

Principal Investigators
Phillip M Rice, INEL
Bradley M Gardner, INEL
Guy G Loomis, INEL
Industry participants to be determined

Research Objective
Develop a remotely controlled conveyance system and an innovative end effector to allow digging and transfer of retrieved waste from the dig-face to the processing or packaging area with virtually no dust generation.

Technology Description
The conveyance system will consist of an automatically guided vehicle (AGV) or gantry crane-mounted device to transport retrieved buried waste. This will be integrated with an innovative end effector for digging and dumping so that the entire system minimizes dust contamination spread until treatment and packaging.

The AGV or gantry crane will be made and tested to remotely convey a variety of waste from the retrieval area to the processing or packaging area. It should be designed to transverse a variety of terrains, to operate in a hazardous environment, and be easily maintained and decontaminated in these environments.

The end effectors consist of detachable buckets, specialized excavator buckets, integral dumping apparatus, or any other mechanism that might facilitate dust-free transfer and dumping of waste. A formal evaluation of forklift/dumpster concepts, gantry crane, and AGV designs will lead to procurement or fabrication of apparatus and conveyance mechanisms to be tested.

Waste Management/Remediation Need
The end effector and AGV development are designed to reduce contamination during waste remediation digging, conveyance, and dumping. These operations have been shown to have the maximum potential for dust spread. Previous problems with dust emissions during funnel dumping operations and in transporting dumpsters over rough terrain will be addressed.

Planned Research
Test alternatives for digging and dumping retrieved buried transuranic waste will be determined. Dumping improvements such as sealing the dumpster to the bucket prior to dumping will be tested for elimination of the soil/waste matrix falling through a distance and displacing a large volume of air. An alternative digging end effector or a detachable excavator bucket to avoid dumping in the retrieval area will be tested. The end effector, gantry crane, and AGV testing will be combined into a unified demonstration at the Cold Test Pit. Testing will involve putting the bucket/dumpster and AGV through a typical set of digging and dumping operations on containers spiked with rare earth tracers.

The major tasks that are planned for this research are:

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete conceptual design</td>
<td>12/01/93</td>
</tr>
<tr>
<td>Complete procurement/fabrication of end effector</td>
<td>07/15/94</td>
</tr>
<tr>
<td>Complete end effector testing</td>
<td>08/01/94</td>
</tr>
</tbody>
</table>

Technology Attributes
- Verify sampling and verification monitoring
- Assist CERCLA and Pit 9 retrieval option assessment
- Examine low dust dumping techniques in a cold environment on an engineering scale
Accomplishments
Two dust control concepts have been tested—misting systems and directed air flow. Dumping using misting systems decreased dust by 40% while directed airflow decreased dust by as much as 70%. An improvement in dust control during digging and dumping of 98% is sought over the present BWID design of gantry crane with cross conveyor and funnel with control of dust by directed airflow and misting.

Technology Transfer
Industry participation will be sought for the end-effector and waste-conveyance systems. The systems developed by INEL scientists and engineers can be transferred to the private sector.
CONTAMINATED MATERIAL EXCAVATION HANDLING AND RETRIEVAL SYSTEM

This technology is being initiated in FY-94

Principal Investigator
J. Gary Carter, Pacific Northwest Laboratory

Research Objective
Design a movable, track-mounted, remote, full-scale, retrieval gantry system that can be placed over a waste trench and retrieve waste packages with containment provided by a localized seal.

Technology Description
The Contaminated Material Excavation Handling and Retrieval System (CMEHRS) will be a large movable building that can be placed over a portion of a buried waste site and retrieve and handle buried objects. The unit could include such manipulators as an industrial-grade, high-capacity blower and vacuum pickup system for contamination and dust control, several large overhead cranes for removing all sizes and shapes of buried objects, master slave manipulators, robotic arm for specialized handling, drum venting station for potentially pressurized sealed drums, shielded work area for in-place glovebox analysis or separations, and airlock for entry and exit to equipment and work area.

Waste Management/Remediation Need
The system will have immediate application for buried radioactive waste retrieval of the Hanford cribs, trenches, and hotspots, and repackaging for contact-handled transuranic waste. Buried hazardous and radioactive waste at any site can be remediated with this system. Remediation and retrieval of localized hotspots are especially suited for this equipment.

Technology Attributes
Designing this system will:
- Incorporate other technologies developed by BWID
- Integrate equipment and technologies developed by other DOE laboratories and the private sector
- Be transferable to the private sector when complete
- Provide a viable hotspot retrieval device

Planned Research
The major tasks that are planned for this research are:

<table>
<thead>
<tr>
<th>Task</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete preparation of conceptual design of containment facility and packaging and handling equipment</td>
<td>06/30/94</td>
</tr>
<tr>
<td>Complete engineering study and prototypic conceptual design of containment facility</td>
<td>09/30/95</td>
</tr>
<tr>
<td>Complete design of prototype retrieval equipment and fabricate prototype retrieval equipment</td>
<td>09/30/95</td>
</tr>
<tr>
<td>Complete field demonstration of prototype equipment</td>
<td>06/30/96</td>
</tr>
</tbody>
</table>

Technology Transfer
The retrieval technology is directly applicable to most of the buried waste at DOE sites. The equipment is ideal for private-sector cleanup of hazardous waste and especially acute hazards at Superfund sites. The unit could be placed into service at completion of the field demonstration as a large-scale operation unit on other DOE sites or in the private sector. The design will be documented in open literature and Pacific Northwest Laboratory documents.

Private-sector participation for developing a prototype system exists.
Conceptual design of the Contaminated Material Excavation Handling and Retrieval System (CMEHRS).
SYSTEM HEALTH MONITORING

This technology will be demonstrated in FY-95

Principal Investigators
Robert J Macdonald, INEL
Robert King, Colorado School of Mines

Research Objective
Develop a health monitoring prediction system for hydraulic, mechanical, and electrical functions of field demonstration equipment

Technology Description
This monitoring system will provide remote operators with information on the status of their equipment. Information such as estimated time to failure and an overall “health of systems” index will be based on sensor and computer algorithm technology. The system will not be just informational, but will use data to limit the operator actions that could cause damage and provide emergency override mechanisms.

Selected parameters of hydraulic, electrical, thermal, mechanical, and other functions of field retrieval equipment will be monitored with appropriately designed sensors. The remote sensor capability demonstrated in the remote area vehicle and excavator with interface to computers will be extended particularly in obtaining failure mode data. Sensors that are available will be linked to developed algorithms contained in software modules. New sensors may have to be developed. The algorithms will analyze trend data in real time to determine failure prediction data on specified BWID equipment.

Waste Management/Remediation Need
System monitoring will assist with the remediation of any type of waste. The sensors will protect personnel while expediting retrieval, reducing exposure, and lowering operating costs. Equipment failure can be mitigated to some extent and contaminant releases associated with repair can be reduced.

Technology Attributes
Improvements in monitoring the health of retrieval equipment have several advantages.
- Decrease equipment downtime and improve retrieval rates
- Decrease exposure to personnel for invasive equipment repair
- Decrease exposure, costs, and damage from operating equipment incorrectly, such as overloading, overheating, and overstressing components
- Optimize remote operations where on-site “feel” of the equipment and potential failure is not possible

Planned Research
The equipment that has the greatest benefit for system health monitoring will be selected for testing. Key components that will be monitored on the test bed will be identified and the failure mode data for components will be acquired. Algorithms that can monitor key components and relate them to the repair data for failure trends will be developed. Predictions of failure cycle and time to failure algorithms will be assembled in artificial intelligence software modules.

The major tasks that are planned for this research are:
- Complete collection of failure data
- Complete interim technology evaluation report
- Deploy health monitoring system on BWID demonstration equipment

Planned Start Dates:
- Complete collection of failure data: 06/01/94
- Complete interim technology evaluation report: 09/30/94
- Deploy health monitoring system on BWID demonstration equipment: 08/01/95

Technology Transfer
The database of failure modes, the interface between sensors and computer software including artificial intelligence, and the application to actual retrieval equipment will have numerous public and private applications. Throughout the DOE complex all remote operations, including remote retrieval, decontamination and decommissioning, and nuclear fuel cycle systems, would find the technology useful. Outside DOE,
System health monitoring and prediction

applications to Superfund retrieval, Department of Defense ordnance remediation, mining, and special hazardous production activities are a few of the commercial applications. Private-sector involvement is being sought for Cooperative Research and Development Agreement (CRADA) participants.
CRYOGENIC CUTTING

This technology will be demonstrated in FY-94

Principal Investigator
Dennis N. Bingham, INEL

Research Objective
Develop and demonstrate the ability to perform cryogenic cutting of large objects during retrieval operations

Technology Description
The system will use high pressure liquid nitrogen and solid carbon dioxide to perform cutting and abrading without the introduction of a secondary waste stream due to cutting media. The effort is focused on deploying an adaptation of the highly effective waterjet techniques used in cutting a surface abrading. This adaptation removes the secondary waste-stream water, which makes waterjet cutting an undesirable option for most waste management and environmental restoration activities. The cryogenic cutting technology will enhance existing fluid systems to deliver high pressure liquid nitrogen and solid carbon dioxide to a sophisticated nozzle. The system will be evaluated by cutting select materials.

Waste Management/Remediation Need
Large objects unearthed during buried waste retrieval operations will require size reduction prior to treatment. Current methods for size reduction include shearing, plasma arc cutting, waterjet cutting, and other similar techniques. Shearing is limited to size-reducing materials that are not too large or too strong for the shears. Plasma arc cutting adds risk to operations due to the flame inherent in the operations and the temperature. As previously stated, waterjet cutting adds an undesirable secondary waste stream to the process. The development of cryogenic cutting will produce a cutting technique that is widely applicable and produces no secondary waste stream.

Technology Attributes
This technology will be used to (a) size reduce multiple material types and (b) eliminate the secondary waste stream inherent in waterjet cutting.

Planned Research
Research will be conducted on (a) enhancements to existing fluid systems for the delivery of liquid nitrogen to the nozzle, (b) development of robust control of the nozzle actuation, and (c) evaluation of cutting on select materials.

The major tasks that are planned for this research are:

Complete system enhancements 06/01/94
Conduct demonstration 06/01/94
Complete technology evaluation report 09/30/94

Technology Transfer
Several companies have expressed interest in collaborating in the development of this technology. Technology transfer mechanisms will be used to form the desired partnerships. Interested parties represent cutting service companies, high pressure pump companies, control system companies, and cryogenic companies. Cryogenic cutting may have wide applicability to site decommissioning where secondary waste streams are of concern.
Primary cryogenic cutting system components.

- Pressure Supply Subsystem
- Fluid Supply Subsystem (LN2 - CO2 - N2)
- Delivery Subsystem
- Cutting Head
- Recovery Subsystem
CRYOFRACTURE TECHNOLOGY

Demonstration of this technology was completed in FY-92

Principal Investigators
Jim Allen, Nuclear Remediation Technologies
Guy G. Loomis INEL.

Research Objective
Demonstrate the Cryofracture technology as a pretreatment for processing retrieved or stored containerized waste.

Technology Description
Cryofracture technology was developed by Nuclear Remediation Technologies of San Diego, California, to demilitarize chemical and biological weapons. The process uses liquid nitrogen to freeze materials to -32°F. The materials are then crushed by a large hydraulic press. The freezing process immobilizes the active components, then they are crushed to fragment the material into treatable pieces. The process replaces conventional shredder operations, which are challenged by heavy structural materials, cables, cloth, aerosol containers. The method was adapted and demonstrated as a pretreatment, size-reduction step in processing transuranic (TRU) waste stored in drums and boxes. The introduction of a secondary waste stream to fracture the container safely is omitted.

Waste Management/Remediation Need
Cryogenic fracturing can be used at buried waste disposal sites requiring retrieval of containers thought to contain hazardous ingredients, or potentially explosive or volatile waste. Potential applications include waste disposal sites and treatment facilities. DOE, Department of Defense, and EPA Superfund sites are candidates for such containerized waste treatment.

Technology Attributes
Cryofracture
- Enhances the chances of success for postretrieval treatment of buried or stored waste
- Results in a more homogenous waste for passive and active assay systems
- Eliminates hazards and risks associated with conventional shredding of pyrophorics and other explosives
- Reduces contaminant spread over nonfrozen shredding

Accomplishments
The Cryofracture research
- Was successfully demonstrated on simulated buried TRU waste containers
- Was successfully adapted to drum- and box-shape containerized, metal, sludge, asphalt, concrete, waste
- Proved the principle of size reducing containerized waste after cryogenic cooling
- Reduced containerized waste volumes up to 47%, fractured 90% of the material to less than 6 in. in size
- Requires about 0.2-1.3 ft³ liquid nitrogen (LN₂) per ft³ of frozen debris fractured, depending on the type of waste and container
- Is estimated to cost 40% more to build and 2.3 times as much to operate as a conventional shredding facility if the added expense for hazardous or explosive operation of the conventional facility is not considered

Research Opportunities
Further research is needed to expedite the process to conserve LN₂. The drilling of holes or otherwise assisting the flow of LN₂ into the waste container is critical in this regard. Economically handling the variety of waste densities typically encountered also needs to be studied. The regulatory guidelines and safety and environmental concerns need to be determined to permit a demonstration on contaminated waste.

Technology Transfer
The system has already been marketed by private industry to the Department of Defense for chemical weapon destruction. Licensing or use by waste-processing commercial entities awaits further waste characterization and establishment of needs. A good working relationship between the INEL and the subcontractor that has a license for the technique was established, as evidenced by the design, modification, and complete testing in four months. Technical reports on this application have been disseminated.
Cryofracture process description

55-gal drum containing simulated waste moving into hydraulic press following liquid nitrogen bath.
CRYOGENIC RETRIEVAL

Demonstration of this technology was completed in FY 92

Principal Investigators
Charles Yemington, Sonsub, Inc
David J Valentich, INEL

Research Objective
Demonstrate how waste and contaminated soils can be contained by cryogenic freezing during remote retrieval

Technology Description
Cryogenic retrieval involves freezing a block of waste and soil with liquid nitrogen (LN₂) circulated through pipes in the soil. Small quantities of water are injected into the soil to promote cohesion of the soil and simulated waste particles. Once the area is frozen, waste and soil blocks are remotely removed from the pit to transfer containers for further treatment.

This technology was demonstrated at the INEL Cold Test Pit, a simulated waste pit containing contamination surrogates and waste. A series of carbon and stainless 2-in steel freeze pipes, approximately 10 ft to 12 ft in length, were driven into three areas of the test pits soil and simulated buried waste. A gantry with a remotely operated jackhammer, hydraulic jack, shears, and grapple was then moved over the frozen area to be retrieved. With the gantry and tools in place, the tools were remotely operated and the frozen soil and simulated waste was excavated and loaded into transport boxes. The jackhammer was used to break up the soil and debris. The shears cut and sized the material, and the grapple picked up the debris and loaded it into transport boxes.

Waste Management/Remediation Need
Cryogenic retrieval is best applied at hazardous sites where the spread of contamination is a high risk or potentially explosive or volatile waste might be encountered. DOE, Department of Defense, and EPA Superfund sites are all candidates.

Technology Attributes
The benefits of cryogenic freezing of buried waste and soil followed by retrieval are:
- Safe retrieval of potentially explosive or particularly volatile waste
- Reduced risk to personnel
- Minimal spread of contaminated dust and soil moisture during waste excavation and retrieval
- Agglomerating contaminated soil particles, reducing risk of generating, spreading, and inhaling aerosolized dust

Accomplishments
Cryogenic retrieval technology
- Was successfully demonstrated full scale
- Demonstrated remote retrieval of simulated buried TRU waste
- Demonstrated containment of contaminant spread over nonfrozen retrieval
- Required 6-7 ft³ of LN₂ per ft² of frozen soil and debris retrieved

Research Opportunities
Further research is needed to refine the design of remote tools, conserve LN₂, and evaluate methods to remove and reuse freeze pipes. The moisture requirements of the soil and their effect on ease of retrieval and contamination control, and the method of water addition and monitoring need further study. The regulatory guidelines, safety, and environmental concerns need to be determined to permit a demonstration at a contaminated location.

Technology Transfer
A good working relationship between the INEL and the subcontractor (Sonsub) was established, as evidenced by the building, testing, and mobilization of a complex building and hardware and implementation of a novel idea in five months. Use for retrieval at other Superfund sites and of explosive material for Department of Defense retrieval could make the technology commercially useful and attractive to decontamination and decommissioning concerns.
Remotely operated gantry deployed retrieval equipment (92-334-2-32).

Liquid nitrogen injection pipes inserted in INEL Cold Test Pit (92-334-2-13).
TREATMENT

Point of Contact
Steven O. Bates
EG&G Idaho, Inc
P.O. Box 1625
Idaho Falls, ID 83415-3710
Telephone: (208) 526-6790
E-Mail: STV @ INEL.GOV
GRAPHITE DC ARC AND IN SITU REAL-TIME MEASUREMENTS

This technology was initiated in FY-93 and is continuing in FY-94

Principal Investigators
Jeffrey E. Surma, Pacific Northwest Laboratory
Dan R. Cohn, Massachusetts Institute of Technology
Charlie H. Titus, Electro-Pyrolysis, Inc.

Research Objective
Demonstrate and evaluate a graphite-electrode, direct-current (DC) arc furnace for processing radioactive waste (both low-level and transuranic) and mixed waste and soil, and use innovative diagnostic tools for monitoring the treatment process.

Technology Description
The Mark II furnace is a refractory-lined, carbon steel vessel measuring 23 ft high and 7 ft in diameter with four soft patch panels around the circumference to provide access for waste feed, glass discharge, and diagnostic equipment. The furnace is designed for semi-remote operation, alpha containment, and ability to process at 1-MVA power giving up to a 1.5 ton/hr processing rate.

The electrode assembly has a unique coaxial arrangement. The outer graphite electrode is 14 in. O.D. and 10 in. I.D. The inner electrode is a solid 6-in. piece of graphite. The electrode assembly can be operated in the transferred arc mode or the nontransferred arc mode (arc between parts of the electrode).

The real-time measurement systems include analytical equipment for measurement of furnace and glass temperatures and exhaust emission in the furnace chamber and offgas line. A millimeter wave radiometer for measuring furnace and glass temperatures is more transparent to the furnace environment than infrared pyrometers. Specially deconfigured plasma sources will be tested for in situ measurement and analysis of gaseous and particulate emission in real time. Molecular emission analysis and particle size and velocity determination are used to monitor composition of solid material at various stages of processing.

Waste Management/Remediation Need
The plasma arc technology can treat any type of buried waste—hazardous, low level, and TRU—along with any contaminated soils and containers. Organics are destroyed and metals (both radioactive and hazardous) are stabilized in a suitable final waste form. Ash and secondary waste and soil can be treated.

Planned Research
The Mark II furnace will be tested at higher throughputs than the Mark I and in a continuous processing mode. The operation of the furnace will be evaluated from the standpoint of materials feeding, glass and metals pouring, electrode design, stability, and overall operability including offgas. A material balance will be established. Submerged and unsubmerged arc operations will be compared.

Molecular emission analysis, particle size and velocity determination, and composition of solid material at various stages of processing will be developed and tested. The continuous online offgas system will be used to assist in the material balance and provide input, along with the temperature sensors to optimize the furnace design.

The major tasks that are planned for this research are

- Complete Series I Mark II testing 04/30/94
- Complete Series II Mark II testing 09/30/94
- Complete process diagnostics development 09/30/94
- Complete report on FY 94 development and testing 09/30/94

Technology Attributes
The Mark II has several advantages:
- It can handle objects as large as a 35-gal drum
- Destruction of limited quantities of hazardous materials can be tested
- The offgas system is suitable for a full-scale production furnace
- The plasma arc can treat any type of buried waste—hazardous, low level, and TRU—along with any
contaminated soils and containers
- The final waste form (slag, solidified residue) is extremely durable and shows similarity to long-life natural analogues
- Incoming waste can be used to decrease offgassing, thereby reducing secondary waste.

**Accomplishments**
An engineering-scale furnace, the Mark I, has been built and demonstrated, and design improvements are ongoing, including development of improved diagnostics. Surrogate waste has been treated with this furnace. A large pilot-scale unit has been built, the Mark II, incorporating offgas treatment, higher power, and throughput. Improved diagnostics include analytical instruments to make spatially resolved measurements of furnace and glass temperatures and to measure gas concentrations both in the furnace and offgas exhaust line. A self-calibrating millimeter wave radiometer, plasma sources, and analytical instruments have been developed and will be used in Mark II testing.

**Technology Transfer**
Other commercial entities have expressed interest in both the melter and diagnostic technology. Technology transfer is occurring with the university (MIT) and industry (Electro-Pyrolysis) partners on the project. Technical progress reports and design data will be transferred to other projects, especially similar vitrification efforts.
This technology was initiated in FY-93 and is continuing in FY-94.

**Principal Investigators**
Gary L. Anderson, INEL
Nick R. Soelberg, INEL

**Research Objective**
Demonstrate, in a currently operational commercial-scale plasma arc melter, the applicability and feasibility of existing plasma arc melter technology for high temperature treatment of transuranic (TRU) and mixed hazardous wastes and burned or stored soils.

**Technology Description**
A plasma arc furnace pyrolyzes and combusts organic materials and melts residual inorganic materials with an electric arc. The ASME/USBOM plasma furnace—a 15 MVA, 15 ton/hr (nominal) electric arc furnace—features three carbon electrodes, cooled sidewalls for skull operation, continuous feed system, offgas treatment system, and slag and metals tapping capability. The resulting molten slag, upon cooling, produces a durable vitrified cast form that may be safely disposed of.

**Waste Management/Remediation Need**
The arc melter could be used to treat a variety of waste containers and matrices containing both hazardous and radioactive substances. It is especially useful whenever a high efficiency destruction of organics is required. It gives a permanent encapsulation of heavy metals and radionuclides in a nonleachable final product.

**Technology Attributes**
The advantages over conventional thermal-processing methods include high temperatures, high enthalpies, choice of inert or chemically active torch gases, and operation with low gas volumes. Additional attributes of this research include:
- Optimal configuration of plasma arc
- Operating characteristics
- Time needed for mixing
- Migration of plutonium and cerium
- Electrical field patterns of plasma arc
- Energy balances throughout system
- Distribution of waste
- AC versus DC melter comparison
- Nonequilibrium chemistry

**Planned Research**
Plasma energy requirements and downstream costs must be reduced, both in equipment for gas handling and cleanup and secondary waste. Experiments will include analysis of slag and metal phases, offgas, and offgas system residues.

The major tasks that are planned for this research are:
- Complete melt campaign for FY-94: 08/31/94
- Establish Cooperative Research and Development Agreements: 09/30/94
- Complete interim technology evaluation report: 12/15/94
- Develop test design for FY-95: 02/01/95
- Complete technology evaluation report: 12/15/95

-Extent of immobilization of radioactive and hazardous waste
-Recovery of valuable metals

**Accomplishments**
The existing offgas system components can be modified for TRU surrogates and heavy metals containment. Approximately 20 to 30 metric tons of simulated waste will be processed in each melt campaign, or about 4 to 6 metric tons per day. Surrogate wastes, including soils, metals combustibles, and sludges, will be prepared and separately incinerated, as appropriate, in preparation for melter processing.

**Technology Transfer**
University, industry, and other laboratory participants are being solicited. Because many private-sector companies are members of the present ASME test consortium, Cooperative Research and Development Agreements (CRADAs) with...
industrial partners are being sought to speed completion of the demonstration project and accelerate technology transfer to the private sector. Test wastes were used in the first melt campaign, test data were reduced and reported, and FY-94 test plans are being prepared to disseminate information.

Continuous tapping of slag to the slag mold.
**PLASMA FIXED HEARTH PROCESS**

BWID demonstration of this technology was completed in FY-93

**Principal Investigators**
Ray Geimer, Science Applications International Corporation
Dan Battleson, Mountain States Energy, Inc, Butte, Montana

**Research Objective**
Demonstrate the applicability of the fixed hearth plasma torch process for the treatment of mixed (radioactive hazardous) wastes and soil to produce a durable waste form for disposal

**Technology Description**
This project involved the performance evaluation of the plasma hearth process (PHP), a fixed hearth plasma arc treatment technology. This is an application of an existing and commercially available technology that has been used for many years for metals processing. Treating retrieved waste with the PHP will destroy the organic fraction of the waste, including hazardous organics.

The PHP also will provide for separation into a reduced metal phase and a vitreous slag phase, which is important because TRU elements readily react to form metal oxides and will preferentially partition to the slag phase. This may allow for disposal of the metal phase as low-level waste, or possibly separation for recycle or reuse. The remaining material, a durable slag, binds the hazardous metals and radioactive contaminants within a vitreous or crystalline matrix, significantly reducing the potential for waste migration.

**Waste Management/Remediation Need**
The technology has application to the treatment and vitrification of hazardous, radioactive (both low-level and TRU), mixed wastes, and contaminated soils. These types of wastes are found buried or stored at DOE site across the complex.

**Technology Attributes**
Mixed waste treatment in a PHP furnace has several potential benefits, including:
- High efficiency destruction of organics
- Separation of metal from slag in the molten state, with TRU components partitioning to the slag phase
- Encapsulation of heavy metals and radionuclides in the final waste matrix
- High-integrity, vitrified final waste form
- Improved criticality control
- Maximum volume reduction
- Smaller offgas rates minimizing particulate entrainment and carryover
- Smaller process equipment
- One-step treatment process (no pretreatment or posttreatment required)
- Capability to process many waste types, including paper, cloth, plastics, metal, glass, concrete, soil, and sludge

**Planned Research**
A new generation PHP is being constructed in FY-94 by the DOE Office of Technology Development’s Mixed Waste Integrated Program (MWIP) for further testing.

**Accomplishments**
Six performance tests were conducted in a pilot-scale PHP facility (three to four barrels of waste per hour) with simulated waste materials consisting of mixed metals (ductile iron, cast iron, steel, aluminum, copper, and brass), metal oxide sludge combustible solids (paper, polyethylene and polyethylene terephthalate, cloth, wood, rubber, etc.), and a combustible sludge. All waste materials were contained in a soil matrix, simulating retrieved waste. Each test consisted of feeding two 30-gal drums containing a simulated waste.

The tests demonstrated successful processing of all material types and compositions with no pretreatment required for all waste categories, processed at a rate of 130 to 550 lb/hr, demonstrated a thorough processing of combustibles, noncombustibles, and mixtures of both, and demonstrated the production of a high integrity final product in a single processing step. The test series demonstrated effective destruction of organics, production of a highly durable and leach resistant vitreous slag, and formation of two distinctly separate phases (metal and slag) in the molten pool.
Fixed hearth and plasma torch at the Retech test facility in Ukiah, California.

**Technology Transfer**
The PHP evaluation is being conducted with Science Applications International Corporation (SAIC) and Retech, Inc. SAIC is planning and conducting the testing at the Retech facility in Ukiah, California. Planning for radioactive testing is under way.
PLASMA CENTRIFUGAL FURNACE

BWID demonstration of this technology was completed in FY-93

Principal Investigator
Dan Battleson, Mountain States Energy, Inc., Butte, Montana

Research Objective
Demonstrate the applicability of the plasma centrifugal furnace (PCF) for the treatment of mixed (hazardous and radioactive) wastes and contaminated soil into an extremely durable waste form for disposal.

Technology Description
The PCF is a rotating hearth plasma torch used for refining titanium and is now being developed for treatment of hazardous and mixed wastes and contaminated soils. In the PCF, waste is fed to a rotating hearth where the waste and molten material are held to the side through centrifugal force. During the rotation, the waste moves through plasma generated by a torch that does not rotate. To remove the molten material from the PCF, the rotation of the hearth is slowed and the slag flows through a central bottom opening.

Waste Management/Remediation Need
The technology has application to the treatment and vitrification of hazardous, radioactive (both low level and TRU) and mixed wastes, and contaminated soils including buried waste types of debris. These types of waste are found at all DOE sites.

Technology Attributes
The PCF technology will render hazardous and radioactive wastes and soils into a highly durable, glassy slag with hazardous inorganic waste components being vitrified and stabilized into the slag. Significant advantages of the plasma process are reduced offgas flows, high organic destruction efficiency, high waste volume reduction, and the ability to treat almost any type of waste in a single step process. The PCF has a nominal feed rate of over 150 lb/hr of buried waste type feeds and soil. However, this technology should be scalable to larger capabilities using multiple plasma torches and larger hearth sizes. The feed system of the current melter is capable of feeding objects as large as 4 in. in diameter.

The current system can handle limited quantities of hazardous (nonradioactive) materials. The processing of radioactive materials is being planned.

Accomplishments
The operating procedures and process rate of the PCF has been established for feeds processed to date (mainly INEL soil). A continuous emissions monitoring system and total hydrocarbon monitoring system meeting the latest EPA standards have been installed at the PCF testing facility in Butte, Montana. A Superfund Innovative Technology Evaluation (SITE) test program has been initiated. Three of the planned 16 runs of the SITE test program are completed. The results indicate that the slag produced in these test runs also passed TCLP standards and greater than 99.999% of organic material was destroyed. Since July 1992, four tests have been completed for BWID. The first test provided a shakedown of the PCF equipment and a reference base (known composition) for future test matrix comparisons. Three other tests involved surrogate waste (INEL soil) spiked with ceric oxide (a plutonium surrogate). Preliminary results of the mass balance from the three tests indicated that less than 0.05% of the cerium surrogate was volatilized into the offgas treatment system. It appears that 99.95% of the plutonium surrogate was retained in the final vitreous waste form.

Technology Transfer
This technology is an integral component of a commercial remediation process that is proposed and being evaluated by INEL Environmental Restoration. Disclosure of this research through professional journals and presentations at technical conferences also will disseminate information about this technology to private sector contractors that may be constructing waste processing facilities.

112
Plasma centrifugal furnace at the
Mountain States Energy test facility
Butte Montana
MODELING OF THERMAL PLASMA ARC TECHNOLOGY

This technology is being initiated in FY-94.

Principal Investigator
Michael G. McKellar, INEL

Technology Objective
Develop a computer model of the plasma arc treatment process, giving the most likely composition of final waste slag and offgas, location of heavy metals, and size and distribution of slag and metal pool.

Technology Description
The computer model of the plasma arc treatment will simulate a variety of plasma arc waste treatment facilities. It will determine the migration of particulate and gaseous contaminants to the offgas both by composition and into the equipment. The contaminants encapsulated within the final waste slag, and effects of molten metal pooling on the chemistry and heat transfer of the arc plasma, also will be modeled. Further data needed to model the chemical aspects of the plasma arc process, but not found in the current databases and model limitations, will be provided.

Waste Management/Remediation Need
Plasma arc modeling will have short-term and long-term advantages in analyzing and improving thermal waste treatment technologies. Knowing the effects of convection within the molten slag and melts, and the thicknesses of the different layers, can help maximize waste loadings and minimize metal offgassing. Lower processing costs can be achieved in understanding the effects of the power input to the plasma arc on the temperature field and heat transfer within the facility. Expedited experimental tests can be achieved, lowering costs and achieving technology use sooner.

Technology Attributes
The model can be used to:
- Develop, optimize, and understand plasma arc technology
- Reduce the operation costs of current arc melters
- Determine the migration of the contaminants during and the location of the contaminants after the process
- Develop designs that are more efficient (i.e., capture more waste within the vitrified product)
- Determine areas in which experiments may most benefit the advancement of the technology
- Understand the cause and effects of the physical processes occurring within the plasma arc facilities.

Planned Research
The major tasks that are planned for this research are:

- Modify FIDAP code to calculate heat transfer 05/31/94
- Validate the two-dimensional axisymmetric transferred DC arc model 06/30/94
- Calculate the effects of molten metal pool on electric field and heat transfer via FIDAP 06/30/94
- Perform chemistry code simulations 06/30/94
- Develop DC melter models 08/31/94
- Complete FY-94 report 09/30/94

Technology Transfer
The model can be transferred for use at other public and private facilities, including specific application at Pacific Northwest Laboratory, Massachusetts Institute of Technology, and the U.S. Bureau of Mines. The experimental work from these labs and furnace manufacturing organizations can aid in validating the code. The intermediate and final codes will be transferred to plasma arc developers and end users.
SECONDARY TREATMENT OF BWID OFFGAS USING NONTHERMAL PLASMA

This technology is being initiated and will be demonstrated in FY-94/95

Principal Investigators
Louis Rosocha, Los Alamos National Laboratory
Peter Kong, INEL
Electric Power Research Institute
University of Illinois

Research Objective
Evaluate the nonthermal plasma (NTP) process for removal of volatile organic compounds (VOCs) SOx/NOx, hazardous compounds, and high vapor pressure metals (HVPMs) in melter offgases.

Technology Description
Nonthermal electrical discharge plasma can promote favorable chemistry for the destruction of hazardous chemicals. Electrical energy directed into the process creates an active environment for destruction of gaseous-based hazardous organics.

Waste Management/Remediation Need
This technology is an alternative nonincineration treatment for volatile organic destruction and metal oxidation in remediation of contaminated soil and direct mixed waste treatment. It also treats secondary waste gases from commonly used treatment processes for mixed waste such as vitrification, incineration, and thermal stripping.

Technology Attributes
NTPs have two major applications for hazardous waste treatment.

- Primary Stage: Treating gaseous-based wastes such as VOCs in stack gas and as stand-alone plasma devices.
- Secondary Stage: Treating the offgas stream of incompletely destroyed waste from primary stage units and incinerators or furnaces.

Planned Research
A laboratory-scale NTP system will be demonstrated for the removal of various organics and HVPMs that are characteristic of a high temperature (>500°C) arc melter operated in a reducing mode. Oxidation of HVPMs and destruction of organics will be assessed in various atmospheres, including those with high particulate loadings and at various flow rates and surge conditions.

The major tasks that are planned for this research are:

- Conduct laboratory scale demonstration of organics and HVPM vapors
- Complete design-determination/scaling tests
- Make decision for prototype system
- Design and construct demonstration equipment

Technology Transfer
Other DOE sites such as Savannah River, Hanford, and Mound and participants in the industrial sector such as the chemical, electrical production, and paper and wood products industry support technology transfer. The Electric Power Research Institute intends to cooperate with DOE on an air-toxics effort through a Cooperative Research and Development Agreement and technology commercialization with the private sector.
Secondary treatment of offgas using nonthermal plasma
This technology is being initiated and laboratory tested in FY-94

**Principal Investigators**
Robert Peters, Argonne National Laboratory  
Leo V Weitzman, LVW Associates

**Research Objective**
Develop, evaluate, and demonstrate STRATEX as an integrated process system of several technologies to process radioactive and hazardous wastes

**Technology Description**
STRATEX is an integrated system to treat contaminated soil and other high volume radioactive and hazardous wastes. Synergistic physical and chemical processes combine thermal desorption, steam stripping, and solidification/stabilization into an efficient treatment system. STRATEX overcomes the inherent heat transfer and turbulence problems with several features.

STRATEX uses low temperature heating from the reaction of the binder and steam mixed with the waste. A low particulate emission is expected because the unit is more compact from intimate heat transfer and the water in the soil is chemically bound rather than violently boiling off. By using a condensable gas (steam), the offgas stream is much smaller and easier to treat than a conventional desorber system. The solidification of remaining inorganic contaminated residue is not affected by organic material interferences on the binding agent, Portland cement or lime.

**Waste Management/Remediation Need**
Many processes will either destroy hazardous organics or stabilize heavy metals. Sequential processes used to treat both types of waste and satisfy requirements of destruction and solidification without taking advantage of synergistic effects are costly, complicated, and good only for small-volume, specialized operations.

**Technology Attributes**
Instead of sequential treatment of thermally desorbing soil and solidification, STRATEX combines both steps in one operation. Compared to typical sequential treatments, STRATEX is less expensive, easier to maintain, able to handle higher volumes, able to handle a greater variety of wastes, and safer in terms of exposure and operation. The research effort will design STRATEX for specific DOE site soils and contaminants, collect reliable data for accurate estimation of performance and cost, and compare design, performance, and cost with existing technologies.

**Planned Research**
A laboratory feasibility study of STRATEX will evaluate and optimize the system's removal efficiency for organic contaminants, volatile metals such as mercury and arsenic, and stabilization of nonvolatile inorganic contaminants. Binder selection, operating parameters, and estimated costs will be determined.

The major tasks that are planned for this research are

- Build laboratory system
  - 04/15/94
- Determine binder/additive requests based on simulated wastes
  - 06/01/94
- Conduct laboratory performance testing with actual waste matrices
  - 12/31/94
- Complete draft lab testing assessment report
  - 12/31/94

**Technology Transfer**
A private independent consultant is involved as a joint participant to assist in timely technology transfer. A private ER/WM company will become involved as a joint participant during the demonstration phase. After technical viability is demonstrated, formal Cooperative Research and Development Agreements will be developed. Other Argonne, DOE, and Department of Defense sites are interested in the technology.

STRATEX is a patented process giving added incentive for privatization and commercial use.
Schematic diagram of the STRATEX process.
**ICE ELECTRODES**

Performance testing of this technology was conducted in FY-93.

**Principal Investigators**
David F. Glenn and Jani C. Ingram, INEL
Don Prescott, Environmental Research and Development

**Research Objective**
Develop and test an ice electrode to remove heavy metals from liquid waste streams and recover valuable metals and minerals for resale.

**Technology Description**
An ice electrode is a conventional electroplating electrode coated with a thin sheath of ice produced by liquid nitrogen-cooled nitrogen gas flowing through an electrode. Bench-scale tests indicate that metals that can be electrodeposited on a conventional electrode can also be electrodeposited on an ice electrode. Preliminary work with metals that do not electrodeposits on conventional electrodes, such as uranium and tungsten, suggests that oxides of such metals can be recovered at an ice electrode. Metals can be recovered simply by allowing the ice to melt.

**Waste Management/Remediation Need**
The ice electrode technology has application in any process that produces metal-bearing waste solutions, including private-sector mining waste streams and metallic DOE or Department of Defense process solutions from product fabrication and cleaning.

**Technology Attributes**
- Recover metals not possible by conventional electrodeposition
- Retrieve oxides of uranium and tungsten
- Allow easy recovery of metals with no additional chemicals needed, such as with precipitation recovery
- Minimize waste generation because the electrode is not destroyed due to the presence of the ice sheath.

**Accomplishments**
- Bench-scale tests determined that all plateable metals are candidates for removal from solution
- Technique can be used in dilute ppm range solutions
- Near 100% deposition efficiency has been achieved
- Pilot-scale reactor has been designed and built.

**Research Opportunities**
A demonstration of the pilot-scale reactor is needed on waste solutions that might be encountered in mining or from waste-treatment streams. Stability and robustness of the electrode and the special case of uranium removal, which is of particular DOE interest, needs research.

**Technology Transfer**
Ice electrode technology will be useful for waste treatment and processes that deal with metal-bearing waste solutions, including private-sector mining waste streams, plating companies, and metal-cleaning operations. Technology gains from treatment of DOE and Department of Defense streams will transfer readily and be of great value to a variety of private concerns.
Bench-scale demonstration of ice electrode technology at the INEL Research Center (92-111-2-3).
Demonstration of this technology was completed in FY93

**Principal Investigators**
Peter Shaw  INFL  
Brenda Anderson  General Atomics  
Douglas Davis  EnVitco

**Research Objective**
Determine if the vitrification coprocessing of radionuclide contaminated nitrate salts and soils is an effective remediation method for destroying the salts while stabilizing the soils.

**Technology Description**
Laboratory scale melting of radionuclide contaminated INEL Pad A nitrate salts and Acid Pit soils was conducted using crucibles in a bench top furnace together at 1550°C simulating ex situ vitrification treatment. The new waste form ranged from a high sodium to more durable borosilicate glass depending on the ratio of Pad A salts (15 to 50 wt%) and Acid Pit soils (40 to 80 wt%) mixed. Glass oxidation reduction and handling properties are controlled by using additives such as boric acid and carbon (0 to 10%). The salt/soil/additive ratios determine the range of glass compositions, maximize mass and volume reduction, durability, and immobilization of hazardous and radioactive metals, and minimize viscosity and offgas generation for wastes prevalent at the INEL and other DOE sites.

**Waste Management/Remediation Need**
The INEL currently stores about 4% of the 254 million kilograms of DOE radiologically contaminated nitrate salt waste. Nitrate wastes are generated at the rate of 7.5 million kilograms per year. The salt waste at Pad A and metal and radiological contaminated soil like that from the Acid Pit provide examples of wastes found throughout the DOE weapons complex. Processing mixed hazardous low level radioactive waste containing uranium, transuranics, cesium, 137/chlorinated solvents, potassium and sodium nitrate salts, chromium and mercury commingled with soil is needed at most DOE sites where radioactive waste is stored.

**Technology Attributes**
Vitrification of nitrate salts and soils
- Completely destroys the nitrate and organic wastes
- Produces high waste form densities of 2.4 g/cc compared to 0.77 g/cc (salt) and 1.57 (soil) g/cc
- Produces durable waste similar in dissolution rate to good high level waste glasses

**Research Opportunities**
The processibility of wastes with a variety of metal and combustible contents would show the robust character of the process. Further waste form definition would help validate the waste loading limits in terms of alkali metals and additives needed.

**Technology Transfer**
The collaboration between DOE/INEL Environmental Restoration and industrial contractors General Atomics and EnVitco provided technology transfer from the inception. The input of a major melter manufacturer and major nuclear treatment company helps to disseminate technology throughout the DOE complex and in other waste processing sites. The use of the technology both from a processibility and waste minimization standpoint make it particularly valuable for commercial marketing.
Melt furnace being opened to remove crucible

Melt furnace annealing oven inside hood

Molten glass flowing into heated graphite mold

Open melt furnace hot crucible about to be poured
CONTAINMENT

Point of Contact
Guy G. Loomis
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415-3710
Telephone: (208) 526-9208
E-Mail: GUY @ INEL.GOV
IN SITU ENCAPSULATION OF BURIED WASTE

This technology is being initiated and demonstrated in FY 94

Principal Investigators
Jerry R. Weidner INFL
Guy G. Loomis INEL

Research Objective
Demonstrate an encapsulation technique using calcium carbonate precipitating solutions injected into buried waste resulting in a carbonate cemented block that is impervious to water migration.

Technology Description
In situ grouting involves the injection of calcium carbonate precipitating solutions into buried waste streams encapsulating them in a carbonate cemented block that is impervious to water migration. The technique can also be used as an intermediate stage to solidify waste to prevent future aerosolization of contaminants should retrieval be necessary.

The concept is an analogue of the natural processes that produce classic sedimentary rocks. Loose unconsolidated soil or sediment is converted into a hard, durable impermeable rock by precipitation of minerals (cement) from groundwater between the particles of unconsolidated materials. The most common natural cements are calcite (CaCO₃) hematite (Fe₂O₃) and various forms of quartz (SiO₂). The existence of such rocks in the natural environment for long periods of time requires that they be in chemical equilibrium with their surroundings. The success of using artificial analogues of natural cementing processes to encapsulate and isolate waste materials hinges on the ability of the aqueous cementing solutions to penetrate and permeate INEL soils.

Waste Management/Remediation Need
Stabilization of 2 million ft³ of buried transuranic (TRU) waste mixed with up to 6 million ft³ of soil at the INEL and similar or greater quantities of low level TRU and mixed waste buried at other DOE sites might be necessary to prevent potential health and environmental hazards.

Planned Research
The research will examine the suitability of using calcite precipitating solutions in experimental bench and field demonstrations. The bench testing will determine compatibility on specific soil types such as found at the INEL, ORNL, Hanford, and Sandia using vendor supplied grout and procedures if these are successful the grout will be field demonstrated.

The major tasks that are planned for this research are:

- Complete laboratory testing 02/01/94
- Iron oxide cement white paper 04/30/94
- Organic polymer cement white paper 04/30/94
- Complete field testing and final report 09/30/94

Technology Attributes
In situ grout technology that is capable of isolating waste material from the natural environment has several unique features. The technology:
- Can stabilize a variety of DOE and Superfund sites
- Is compatible with complex mixtures of various contaminants
- Isolates and encapsulates buried materials containing hazardous waste, radioactive waste, and TRU element waste
- Is applicable to various waste forms and surrounding materials and isolation of buried structures such as waste storage tanks
- Has a natural analogue both in formation and longevity in limestone
Accomplishments
Encapsulation at the INEL using particulate grout and the Richland Hanford Operations technique for grout injection has been studied. The grout was able to penetrate large voids but did not penetrate the soil void space. Organic solution grouts, which are finer in grain structure, have been successfully demonstrated at Oak Ridge National Laboratory (ORNL). Microfine cements have been successfully used at Hanford in a rocky/sandy soil.

Technology Transfer
The technology participants from the INEL and a private vendor will aid in technology transfer. Additional industrial and university participants will be involved in the program as requirements and needs become better defined. The data obtained from each of the activities will allow technical evaluation for remediation by private, DOE, and ER/WM concerns.
INNOVATIVE GROUT

This technology is being initiated and will be demonstrated in FY-94

**Principal Investigator**
Guy G. Loomis, INEL

**Research Objective**
Demonstrate an innovative grouting concept for buried waste retrieval involving a three-step process in a field environment. The first step is to grout the waste, causing an agglomeration of fine soil particles that may have become contaminated. Next, the monolithic grouted block is fractured using a demolition grout. Finally, the debris is excavated in a relatively dust-free environment with remotely controlled equipment.

**Technology Description**
The overburden soils of the buried waste pit first are grouted to form a barrier to spray back during the grouting of the soil/waste seam below. After curing, the soil/waste matrix is grouted with a Case Grande drill apparatus with special fittings at the surface for contamination control. The grout material is jet grouted with up to 8,000 psi pressure into the soil/waste matrix. The fine dry clay interstitial soils will become intimately mixed with the grout and the grout will readily fill voids in the waste matrix. The exact grout formulation and compatibility with INEL soils will be determined by prior bench experiments. Once grouted, the soil waste pit will be fractured with a demolition grout. Prior to this step, the pit could be left in an interim storage mode for up to 20 years prior to retrieval. Once the fracturing has occurred, a bridge crane apparatus with grapples, shears, and jackhammers will be placed over the pit. The excavation should require minimal contamination control because the contaminants should be locked in a grouted matrix.

**Waste Management/Remediation Need**
There are 2-million ft\(^3\) of transuranic (TRU) waste commingled with up to 8-million ft\(^3\) of soil in shallow land burial at the INEL. Other DOE sites such as Hanford also have buried waste. Retrieval and treatment of this waste is one of the options being pursued. Prior retrieval efforts and studies have emphasized the importance of contamination control during any plutonium handling operation, consequently, any enhancement of dust control will help to promote a successful operation. Plutonium uptake limits are extremely restrictive, therefore, there are no alternatives to strong contamination control strategies.

**Planned Research**
The major tasks that are planned for this research are:

- Conduct bench-scale experiments to determine grout formulations
  - 01/31/94
- Conduct field demonstration at the INEL Cold Test Pit
  - 09/30/94
- Complete evaluation report
  - 09/30/94

**Technology Attributes**
The innovative technology accomplishes buried TRU waste retrieval with no contamination spread. This grouting technique:
- Allows leaving the waste in a confinement matrix prior to retrieval and treatment
- Contains the spread of contaminated soils by agglomeration of fine soil particles in the grout
- Eliminates the need for elaborate contamination control strategies during retrieval and handling

**Technology Transfer**
The concept could be transferred to the INEL Environmental Restoration Program for use by the private sector for remediation of TRU pits and trenches. The private sector could also use this technique on buried waste sites where contaminant spread is a problem.
MONOLITHIC CONFINEMENT

This technology will be demonstrated in FY 94

Principal Investigators
Jerry Alexander and Steve Phillips
Westinghouse Hanford Company
Brookhaven National Laboratory

Research Objective
Create a barrier to waste migration below buried waste sites in a basaltic field environment and verify success by examining the inner granular regions for penetration of grout by borehole drilling

Technology Description
The technique will use Casa Grande drill apparatus to drill into basaltic formations and apply jet grouting, a grout that fills the inner granular cracks in the basalt. This technique also simultaneously locks in contaminants that may have spread to regions below buried waste

Waste Management/Remediation Need
There are 2 million ft$^3$ of transuranic waste commingled with up to 8 million ft$^3$ of soil in shallow land burial at the INEL. Underlying this buried waste is hundreds of feet of intermittently fractured basalt. Migration of volatile organics and other contaminants to the aquifer below the basalt must be minimized to maintain water quality

Technology Attributes
The technology provides a positive barrier to further migration of buried waste contaminants to potential underlying aquifers. It has the following features
- Complements an overall strategy of total confinement
- Eliminates the further migration of contaminants actually in the basalt

Planned Research
A Casa Grande drill apparatus will be mobilized to the INEL. A specially selected grout matrix will be applied to a basaltic test bed at the INEL's Box Canyon site using the drill in a jet grouting mode. Core samples will then be analyzed to evaluate the confinement for potential migration routes in the basalt/grout interface

Technology Transfer
The technology will be provided to Environmental Restoration Programs for implementation by the private sector for remediation of pits and trenches. The private sector could also use this technique on any buried waste site where contaminant spread is a problem
APPENDIX A
COLD TEST PIT

Point of Contact
Guy G. Loomis
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415-3710
Telephone: (208) 526-9208
E-Mail: GUY@INEL.GOV
COLD TEST PIT

An area 40 ft (12 m) wide, 228 ft (68 m) long, and about 10 ft (3 m) deep was excavated in 1988 about 600 ft (183 m) south of the Subsurface Disposal Area (SDA) in the Radioactive Waste Management Complex (RWMC). This area, known as the Cold Test Pit, was initially divided into five cells, with each cell representing a different configuration of the waste. The cells contain randomly dumped barrels, randomly dumped barrels and boxes, stacked barrels, stacked boxes, and the large objects pit (the waste seam is about 8 ft thick with a 4–5 ft soil cap). Each barrel and box was filled with simulated waste in specific, marked cells and backfilled in the same manner as the SDA waste pits were constructed between 1953 and 1970. Items such as metals, tools, plastics, concrete, asphalt, wood, and simulated sludge were placed in each container.

Cardboard containers were used to hasten deterioration of the barrels and boxes—a condition most likely to be encountered at the SDA. Water was also sprayed on the containers just prior to burial to accelerate the deterioration.

In order to simulate the presence of radioactive waste for migration and detection purposes, rare earth tracers were placed into each container. These tracers are valuable when measuring the effectiveness of contamination control technologies. Only one kind of tracer was placed in each cell. No tracers were placed in the large objects pit. The following kinds of tracers were placed in each of the cells:

- Randomly dumped barrels — dysprosium
- Randomly dumped barrels and boxes — ytterbium
- Stacked barrels — terbium
- Stacked boxes — neodymium

Two additional test cells were added in 1992 to support BWID's characterization and retrieval demonstrations. The total size of the cells is 40 ft (12 m) wide, 43 ft (13 m) long, and 12 ft (3.7 m) deep. The retrieval cell was excavated in the FY-93 Remote Excavation System proof-of-principle demonstration.

A 1993 shallow characterization cell was added to support the Trench Dig-Face Demonstration and will be used as a calibrated test cell for future demonstrations. The dimensions of this cell are 32 ft (9.6 m) wide and 8 ft (2.4 m) long.

The Cold Test Pit is being used as a simulated waste disposal area to test and demonstrate characterization, retrieval, and treatment technologies. It provides known targets and waste forms for accurate evaluation/calibration of procedures, technologies, and equipment tested. Testing at the Cold Test Pit reduces hazards to personnel and the environment otherwise unavoidable in an actual disposal area.
Layout of INEL Cold Test Pit (Q93 0209).

Graphic layout of the INEL Radioactive Waste Management Complex and the Cold Test Pit (R93 1536).