HY-95 TECHNOLOGY CATALOG

TECHNOLOGY
DEVELOPMENT
FOR BURIED WASTE
REMEDIATION

DOE Environmental Management
Office of Technology Development
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ABSTRACT

The U.S. Department of Energy's (DOE) Buried Waste Integrated Demonstration (BWID) program, which is now part of the Landfill Stabilization Focus Area (LSFA), supports applied research, development, demonstration, and evaluation of a multitude of advanced technologies dealing with underground radioactive and hazardous waste remediation. These innovative technologies are being developed as part of integrated comprehensive remediation systems for the effective and efficient remediation of buried waste sites throughout the DOE complex. These efforts are identified and coordinated in support of Environmental Restoration (EM-40) and Waste Management (EM-30) needs and objectives. Sponsored by the DOE Office of Technology Development (EM-50), BWID and LSFA work with universities and private industry to develop technologies that are being transferred to the private sector for use nationally and internationally.

This report contains the details of the purpose, logic, and methodology used to develop and demonstrate DOE buried waste remediation technologies. It also provides a catalog of technologies and capabilities with development status for potential users. Past FY-92 through FY-94 technology testing, field trials, and demonstrations are summarized. Continuing and new FY-95 technology demonstrations also are described.

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INTRODUCTION

The U.S. Department of Energy (DOE) Office of Technology Development (EM-50) has initiated a number of comprehensive research, development, demonstration, testing, and evaluation programs to provide innovative and emerging technologies and technology systems. In an effort to focus resources and enhance cost effectiveness, EM-50 has established an assortment of integrated demonstrations or focus areas. Their purpose is to evaluate a group of related technologies individually or as an engineered system in correcting specific areas of waste management and environmental problems.

The Buried Waste Integrated Demonstration (BWID) program has been transitioned into the Landfill Stabilization Focus Area (LSFA). The object is to demonstrate emerging technologies that offer promising solutions to the problems associated with the remediation of buried waste, particularly difficult remediation problems found across the DOE complex related to transuranic (TRU) contaminated buried waste.

The scope of projects within these programs includes engineering development and demonstration of technologies that will support the remediation of hazardous and radioactive waste by characterizing, retrieving, treating, and/or containing it. An estimated 3.1 million cubic meters is buried or stored throughout the DOE complex. Typical constituents include construction and demolition debris, laboratory equipment and disposables, process and maintenance equipment, and decontamination materials. The waste at these various sites has been buried (belowgrade) or stored (abovegrade) in trenches, pits, tanks, cribs, and buildings and on asphalt pads. Much of the buried waste is believed to be contaminated with both hazardous and radioactive materials, including transuranics. The associated contaminated interstitial soil increases the total volume to be remediated significantly.

An engineered systems approach is used to develop and demonstrate technologies. Using this approach, the program first defines the steps needed to remediate waste by identifying high-level (general)

systems, called configuration options. Next, input, output, and functional performance requirements for specific technologies are determined by overall system performance objectives. During laboratory and field testing, technologies are then evaluated against technology-specific performance objectives, and consequently high-level system objectives, to assess both individual technology performance and impact on the overall system performance.

Next, technologies are combined to conduct integrated field trials. These field trials consist of partial or full-scale engineered systems and serve to validate technology performance within an integrated remediation system. Ultimately, integrated and engineered systems or major components of such systems are delivered to the waste remediation community. These can be commercialized and applied with minimal further development and testing.

During the tenure of the program, BWID has conducted field trials of specific technologies and engineered system demonstrations. After field trials, technology systems require

further engineering development and demonstration. Future demonstration activity will be implemented under the EM-50 new focus area concept, specifically under the LSFA.

The purpose of this report is to summarize the technical development activity as applied to buried waste remediation. The first section of the report summarizes the program and systems engineering context under which these technologies have been developed. This includes a summary of the problem being addressed, the objectives of the work, the engineered systems technology development strategy that has been followed, and a systems technology roadmap to allow the reader to locate and contextually identify technologies.

The second part of this report is a technology catalog consisting of summaries of each technology system. Included in each summary are the waste management need being met, the specific research objective of the work, a description and attributes of the technology systems being developed or demonstrated, a summary of technology

transfer activities, and the names of the principal investigators doing the work.

The appendices contain a description of the Idaho National Engineering Laboratory (INEL) Cold Test Pit and Characterization Cell, and public involvement activities.

Drums and boxes buried at Savannah River Burial Complex.

Burial of drums and boxes at the Idaho National Engineering Laboratory in 1969 (69-61-39).

THE DOE BURIED WASTE PROBLEM

The amount of buried waste located throughout the DOE complex as of 1990 is estimated at approximately 3.1 million cubic meters. The DOE sites where this waste is predominantly located are Hanford, Savannah River, the Idaho National Engineering Laboratory (INEL), 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 with both hazardous and radioactive materials. DOE buried waste typically includes TRU-contaminated radioactive waste, LLW, hazardous waste per 40 CFR 261, greater-than-class-C waste per 10 CFR 61.55, mixed TRU waste, and mixed LLW. Interstitial soils are

also 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, etc.).

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 should be transferable for potential applications at other DOE buried waste sites.

Approximately 0.3 million cubic meters of waste is buried at RWMC. Typical disposal containers included

steel drums (30, 40, and 55 gal), cardboard cartons, and wooden boxes (up to 105 x 105 x 214 in.). Larger individual items were disposed of separately as loose trash. Degradation of the waste containers is believed to have resulted in contamination of the soil. Estimates of contaminated soils at the INEL are in the order of 0.9 million cubic meters.

In the past, incomplete records were kept, and as a result, the exact nature of the contamination is uncertain. Through the years, some of the waste-containing drums and boxes have leaked and their contents mixed, creating another kind of problem. Some have potentially spread and migrated to the groundwater.

These waste disposal sites must be remediated or cleaned up with the existing and evolving statutory and regulatory requirements. These requirements include the Federal Facility Agreement and Consent Order, as well as other interagency agreements with legally binding milestones.

Early trench burial practice at Oak Ridge National Laboratory (ORNL 41946).

Large containers including plastic bags, boxes, and drums buried in soil at the Hanford Site.

THE TECHNOLOGY DEVELOPMENT MISSION

The development and demonstration of buried waste technologies supports Environmental Restoration (ER) and Waste Management (WM) needs. Significant technological advancements are required to safely and cost effectively complete the remediation of buried waste within the time frame defined by various Federal Facility Agreement and Consent Orders with the DOE, U.S. Environmental Protection Agency, and various host states. BWID has supported development and demonstration of a suite of technologies that are integrated with commercially-available baseline technologies to form a comprehensive remediation system for the effective and efficient remediation of buried waste disposal throughout the DOE complex. This particular program is now part of LSFA.

Technology development and demonstration activities are based on their potential contribution to overall remediation systems as well as individual performance potential. Site and waste characterization, retrieval, treatment, and containment technology development is guided by technical objectives that are derived

by the performance needs of the system they support.

Site Characterization

Site characterization technologies provide physical, chemical, and radiological information and interpretation of near-subsurface waste and other objects, and associated containment features. The buried waste remediation community needs nonintrusive technology to characterize the size, shape, depth, physical orientation, and constituent makeup of near-subsurface waste objects. This information will support the planning and execution of future remedial actions.

BWID has been sponsoring engineering development of a number of technologies such as advanced ground penetrating radar, tensor magnetic gradiometry and magnetometer survey instrumentation, and various shallow applications of classical electromagnetic geophysics techniques as a solution to this community need. Each of these performs functions where gaps in existing technology prevent system performance objectives from being met. The goal of this work is to

develop an integrated system that will be capable of presenting to the remediators an image-like representation of the near subsurface.

Pre-retrieval characterization and digface technology will be demonstrated as part of an integrated waste remediation system at an INEL cold test in 1995 and operated as part of a hot remediation at Brookhaven National Laboratory in 1995 and 1996. In addition, digface instrumentation will be used in remediation operations at Fernald in 1995. Additional hot demonstrations are planned at the INEL in 1996. Radar and magnetometer measurements will also be done at the Custer Battlefield in support of the National Park Service in 1995. Commercialization of BWID-engineered products, which began in 1994, will continue in LSFA. Characterization products being field demonstrated in 1995 and close to commercialization include a three-dimensional imaging ground penetrating radar and an imaging infrared species detector.

Waste Characterization

The function of waste characterization is to nonintrusively characterize

waste containers, with emphasis on 55-gal drums, to qualitatively and quantitatively determine the waste constituents. This information is required to allow the shipment of the containers to a treatment or storage facility, which requires meeting the individual facility's Waste Acceptance Criteria (WAC). The suite of technologies for waste characterization that LSFA is sponsoring is made up of the Combined Thermal Epithermal Neutron (CTEN) interrogation system, the Active and Passive Computed Tomography (A&PCT) gamma interrogation system, the Digital Radiography and Computed Tomography (DRCT) x-ray scanner, and the Waste Assay Measurement Integration (WAMIS).

The waste characterization technology goals that LSFA has identified are to nonintrusively and accurately

- (a) determine the waste matrix,
- (b) obtain spatial information,
- (c) determine any fissile material quantity,
- (d) determine the specific nuclide concentration, and
- (e) determine the quantity of any free liquids in 55-gal waste drums.

This information within certain precision and accuracy limits will allow for the determination that the container can be treated usually when the concentration is less than 100 nCi/g TRU. If greater than this, waste goes to long-term storage such as the Waste Isolation Pilot Plant. Additionally, waste transportation rules (Department of Transportation) limit the amount of free liquids allowed within a container. These characterization data are best obtained through nonintrusive means to limit the risk of worker exposure and risk of contamination release.

The development of these technologies and research activities on the individual systems is occurring at several different DOE national laboratories, universities, and private businesses. The CTEN development is at Los Alamos National Laboratory and a prototype has been mechanically constructed and is presently being completed electronically. The system software is being developed by Canberra through a Cooperative Research and Development Agreement (CRADA). Overall system integration testing on surrogate drums is planned.

The A&PCT development is at Lawrence Livermore National Laboratory and evaluation testing is under way. The development of advanced algorithms used to reconstruct the acquired data is occurring through a partnership with the University of California-San Francisco. A similar system called the Waste Inspection Tomography system is being developed in conjunction with Bio-Imaging Research and will be placed in a portable trailer. DRCT is being developed by the Idaho State University and the INEL and is undergoing testing at the campus. The scanner is running surrogate drums and will start testing on real drums during the summer of FY-95. A waste assay system is also being developed at the INEL including data processing and display for other individual systems. It will integrate and process all the data and display the results. The system is under development and was to be ready for an initial demonstration of previously acquired data in February 1995.

The testing of technologies on surrogate drums and real waste drums will continue under LSFA.

Improvement of existing algorithms and development of new computer support aids will improve the final data accuracy. Specific activities that LSFA is planning to help achieve these goals are:

- Complete testing of all of the systems by mid FY-96
- Move systems to the INEL for an integrated demonstration
- Conduct the integrated demonstration in late FY-96
- Use technologies proved successful at the INEL Stored Waste Examination Pilot Plant (SWEPP) in FY-97.

Retrieval

Retrieval technologies provide methods of retrieving buried TRU waste for both hot-spot applications and full pit and trench removal. The risk to human health and environment from the radioactive and hazardous constituents of the buried waste must be mitigated by these technologies. Using remote operation, operators need to efficiently excavate and retrieve overburden and buried waste matrix with little or no human exposure. Similarly, they must be able to maintain and service

the equipment so it does not become part of the problem. During retrieval, the equipment may encounter corrosive, explosive, and radioactive materials, and must avoid spread of contamination within the working enclosure. New retrieval technologies are needed to accomplish this activity.

BWID has examined retrieval of buried waste involving overburden removal, soil/waste matrix freezing combined with remote retrieval equipment, effectiveness of conventional excavators using surrogate waste, contamination control during retrieval, remote conveyance of waste, and remote excavation and retrieval.

The engineering and field demonstration of these technologies will result in data necessary to provide confidence in ER Records of Decision. Commercial partners and publication of results will make these technologies available to the waste remediation community.

In 1995, LSFA is sponsoring a field test of integrated selective retrieval technologies using cooperative telerobotic crane-mounted arms and vacuum systems, as well as self-guided vehicles for conveyance of waste. LSFA will be cooperating with the INEL Pit 9 remediation activity to ensure technical exchange. During 1996, selective retrieval of chemical disposal pits will be performed at Brookhaven National Laboratory in collaboration with EM-40.

Treatment

Waste treatment processes retrieve waste into a stable form that meets the minimum acceptance criteria of the final waste repositories. Important physical characteristics specified by most acceptance criteria are (a) significant volume reduction, (b) destruction of organics, and (c) creation of a stable environmentally benign waste form. Buried waste remediators need robust treatment technologies that will completely process the widely diverse kinds of retrieved buried waste. The technologies should be integrated to perform from whatever pretreatment is required to whatever final operation is needed to obtain

the stable final waste form. The waste that the system must process could be solid, mixed, hazardous, and radioactive.

Additionally, it could be in the form of combustibles, metals, soil, sludges, and their associated structures (i.e., drums, boxes, large metal objects). The treatment process should not be limited and it may involve some initial pretreatment (possibly sorting) done during retrieval with the significant part done in a treatment facility. The treatment operations conducted at the treatment facility may use a combination of thermal, chemical, biological, physical, or radiological methods for all or part of the waste streams.

Because of its goal of near-term results, LSFA has focused its resources predominantly with ex situ thermal treatment. Its accomplishments to date have been significant. It has sponsored engineering development and demonstration tests of five different melters during the period of FY-91 to FY-94. In FY-95, LSFA selected the DC Plasma Arc Melter for further technology development along with associated melter process diagnostics.

The engineering development of the process diagnostics was so successful and innovative that the researchers were awarded a prestigious R&D 100 award for their work with a millimeter wave radiometer. Ultimately, the diagnostics will be used in a control scheme to ensure proper melter operation and adherence to proper regulatory discharge limits. The DC Plasma Arc Melter along with the development of melter process diagnostics was judged to offer the best near-term capability for treatment with regard to (a) the ability to process a wide range of waste types, (b) the apparent ease that the technology process operations could be scaled up to to handle large-sized waste, (c) the apparent ease of converting the process to a radioactive contaminated operating environment, and (d) the innovative diagnostics ability of precise control of the process. Two of the diagnostic tools are currently ready for the commercial sector. The project also assisted in the initial application of the centrifugal furnace, which resulted in its selection for Pit 9.

The goals for treatment technology are to develop and demonstrate a robust treatment system including a

radioactive demonstration on actual waste with acquired valid data. This will enable the technology to be selected for an actual waste remediation project (via a record of decision) or become commercialized. An additional goal is to continue development and testing of the process diagnostics to the point where utilization/commercialization in the private sector for a wide range of similar environments will also occur.

Future activities that will help accomplish these goals are (a) continued development and demonstration of the diagnostic tools (with actual radioactive contaminated waste starting in 1995), (b) continued nonradiation melter testing, and (c) initiating some radiation melter testing in 1995. These activities are planned to address some particular site and waste specific needs.

Containment/Stabilization

Containment/stabilization technologies provide in situ disposal techniques to prevent migration of contaminants from buried waste and prevent subsidence of that waste. Application of these technologies

involves creating multiple barriers and applying physical stabilization. Both of these functions must be stable over geological time periods.

The waste management community needs practical commercial technologies to mitigate contaminant migration and provide physical stabilization of buried waste. Both barriers and waste forms must be stable over geologic time periods. Assessing performance in the near term by verifying integrity directly and in the long term through monitoring of the surrounding environment must be part of these technologies.

BWID has sponsored two proof-of-concept field tests using jet grouting of Portland cement. One was for stabilization of buried waste in pits and the other was monolithic confinement of waste above basalt inner beds. Iron and calcium slurries mixed to form natural analog materials were lab tested as a longer lasting replacement substance for hydraulic cement when injected into soil and waste. In situ confinement and stabilization demonstrations and trials result in technologies considered ready for use or information transfer-

able to ER for use in evaluating records of decision of buried waste.

During FY-96, a field demonstration using hematite (iron oxides) or apatite (calcium fluorophosphates) materials to create geologically stable monolith in the buried waste will be performed. Permeability and stability will be examined.

The buried waste expo held in August 1994 in Idaho Falls attracted government and industry representatives (94-890-6-10).

THE ENGINEERED SYSTEM AS A SOLUTION TO THE BURIED WASTE PROBLEM

The LSFA has adopted BWID's engineered systems approach to developing and demonstrating technologies. The BWID engineering approach first defines the functions that need to be performed by remedial technologies. This is done in an integrated, top-down fashion. First, a system analysis is performed to identify and develop high-level systems, called configuration options, for the remediation of buried wastes. These options fall in three categories: Retrieval and Ex Situ Treatment, In Situ Stabilization, and Containment. Technical requirements for each of these system configurations was derived from the functional and operational performance needs of the end users. Input, output, and functional performance requirements for specific technologies are then determined by overall system performance objectives.

During testing, technologies are evaluated against technology-specific performance objectives, and consequently, high-level system objectives to assess both individual technology performance and impact on the overall system performance.

Following development and testing of individual technologies, LSFA combines technologies to conduct integrated demonstrations. These demonstrations consist of partial or full engineered systems and serve to validate technology performance within an integrated remediation system. The purpose is not only to evaluate the individual performance of a technology, but also to evaluate the performance of all or portions of the complete remediation system. Another purpose is to deliver integrated, engineered systems or major components of such systems to the waste remediation community that can be commercialized and applied with minimal further development and testing.

Below are overviews of each of the baseline configuration options that are the basis for technology requirements. Each of these options contains certain common functions: a preactivity site characterization function to define the spatial distribution and constituent makeup of the buried waste, a treatment or stabilization step, and final disposal. The waste may be left in place in a treated or contained/stabilized configuration, or may be retrieved. Retrieval may occur either prior to or

following treatment. Technologies presented in this document perform identified functions within these configuration options. These are presented as technology roadmaps in this report.

Retrieval and Ex Situ Treatment

The Retrieval and Ex Situ Treatment configuration option consists of 39 subelements. These are divided into the following classes of activities:

1. Waste/site characterization
2. Belowgrade isolation
3. Abovegrade containment
4. Overburden characterization
5. Overburden removal/waste retrieval/conveyance
6. Size reduction
7. Assay and packaging
8. Transportation
9. Treatment
10. Assay and packaging.

Activity outlined by this option can be summarized as follows. Once the pits and trenches are characterized and their contents exhumed, the waste debris/soil is packaged and transported to a treatment facility located adjacent to retrieval operations. Treatment will involve size reduction and metal sorting. The remaining nonmetallic waste streams

will be incinerated and recombined with the sorted metals prior to a final high temperature thermal treatment. Final waste forms will be assayed and designated as LLW or TRU.

In Situ Stabilization, Treatment, and Monitoring

In Situ Treatment and Retrieval

The In Situ Treatment and Retrieval configuration option consists of 22 subelements. These are divided into the following broad classes of activities:

1. Waste/site characterization
2. Belowgrade isolation
3. In situ treatment
4. Abovegrade containment
5. Overburden characterization
6. Overburden removal/waste retrieval/conveyance
7. Size reduction
8. Assay and packaging.

Activity outlined by this option can be summarized as follows. Initially, the buried waste site will be characterized to define or validate major waste constituents and pit and trench physical boundaries. Next, preparatory actions based on risk assessment will be taken to isolate a given volume for treatment. These actions include site preparation,

abovegrade confinement, and the installation of vertical barriers. Isolation will proceed in increments, with internal vertical barriers as interim, and external or peripheral as permanent. Eventually, all pits and trenches will be surrounded by permanent barriers.

As each area, or cell, is isolated, it will be treated in place (in situ) with the selected method of treatment based on the reduction in risk provided. During the isolation and preparation phase, a temporary cap and/or a "best effort" horizontal bottom barrier may be emplaced to provide additional isolation. The contained waste volumes will next be treated in place, and the treated volume monitored during an interim assessment period. Following the assessment period, the treated volume will be size reduced, excavated, sorted, and assayed for final action and disposal decisions. Also included in this configuration option are support functions to meet requirements for confinement, ventilation, offgas treatment, and residuals disposal.

In Situ Treatment and Monitor

The In Situ Treatment and Monitor configuration option consists of 11

subelements. These are divided into the following broad classes of activities:

1. Waste/site characterization
2. Belowgrade isolation
3. In situ treatment
4. Monitor.

Activity outlined by this option can be summarized as follows. Initially, the buried waste site will be characterized to define or validate major waste constituents and pit and trench physical boundaries. Next, preparatory actions based on risk assessment will be taken to isolate a given volume for treatment or stabilization. These actions include site preparation, abovegrade confinement, and the installation of vertical barriers. Isolation will proceed in increments, with internal vertical barriers as interim, and external or peripheral as permanent. Eventually, all pits and trenches will be surrounded by permanent barriers.

As each area, or cell, is isolated, it will be treated or stabilized in place (in situ) with the selected method of treatment based on the reduction in risk provided. During the isolation and preparation phase, a temporary

cap and/or a "best effort" horizontal bottom barrier may be emplaced to provide additional isolation. The contained waste volumes will next be treated or stabilized in place, and the treated volume monitored during an interim assessment period with a temporary cap in place. Volatile organics will be removed from the volume through a vapor extraction process. Following the assessment period, a permanent cap and additional permanent barrier will be installed as necessary, and long-term monitoring will begin. Also included in this configuration option are support functions to meet requirements for confinement, ventilation, offgas treatment, and residuals disposal.

Containment

The containment configuration option consists of 11 subelements. These are divided into four broad classes of activities:

1. Waste/site characterization
2. Belowgrade isolation
3. Abovegrade containment
4. Monitor.

Activity outlined by this option can be summarized as follows. Initially, the buried waste site will be charac-

terized to define or validate major waste constituents and pit and trench physical boundaries. A detailed elevation will also be prepared of the area. The overburden will be shaped, by addition only, to facilitate drainage off a cap. Next, interim and permanent vertical barriers will be installed surrounding the pits and trenches. These will be installed in increments, with internal vertical barriers as interim, and external or peripheral as permanent. Eventually, all pits and trenches will be surrounded by permanent barriers.

As each area, or cell, is contained within vertical barriers, it will be covered with a temporary cap. Also, during the barrier and temporary capping activity, a "best effort" horizontal bottom barrier will be emplaced. The contained waste seams will next be monitored and an interim assessment performed. Beginning at this time, and continuing for a period of 10–50 years, a vapor extraction activity will be performed, followed by a permanent cap final action. Also included in this configuration option are support functions to meet requirements for confinement, ventilation, offgas treatment, and residuals disposal.

THE TECHNOLOGY DEVELOPMENT PROCESS

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 Environmental Restoration and Waste Management (ER/WM) remediation objectives. LSFA has developed a strategy based on developing and demonstrating technologies that fit into an overall cradle-to-grave system for buried waste remediation.

Technology Needs

The technology development process focuses on the waste remediation problems of ER/WM to address their needs. The process uses a systems approach to define the functions that need to be performed by advanced remedial technologies. A detailed system analysis was initiated in FY-92 to identify and develop options of overall systems for the remediation of buried wastes. ER/WM sites from across the DOE complex were assessed including Savannah River,

INEL, Los Alamos, Oak Ridge, and Hanford. The advanced remediation technologies being developed by LSFA support various critical elements of these overall remediation systems.

LSFA, using these overall systems, identifies areas of technologies that, if they are advanced, will make the DOE buried waste remediation process safer, faster, better, and cheaper. Based on this input, LSFA then establishes needs that specify these identified areas. Proposals from DOE national laboratories, other laboratories, private industry, and universities are selected that address these research needs. The needs define remedial technology areas where inadequate, marginal, or no technology exists and the time frame to provide input to the remedial decision processes.

Technology development and demonstration proposals are solicited and evaluated to determine their potential to support the ER/WM applications. The LSFA program sponsors research on some of these proposals based on how well they address the needs, development risk, and available resources. The time

frame prior to ER/WM decision milestones is considered to be the prime window of opportunity to develop more cost-effective and efficient solutions for buried waste remediation needs.

Technology Development

The overall continuum of technology development ranges over basic research, applied research, exploratory development, advanced development, engineering development, prototype demonstration, and commercialization. The technology development that LSFA sponsors starts with fairly advanced concepts that may require some minimum advanced development, engineering development, and prototype demonstration. In general, LSFA will not sponsor concepts that are outside this range of technology development. The lower limit of advanced development is set because LSFA must obtain payoff with technology development over the short term. The upper limit is set because LSFA, as part of a government laboratory, cannot directly commercialize its technology products. This is left to the private sector.

Those proposals that are selected to be funded when developed become an LSFA system. A system is an integration of a number of technologies that function together in a coherent manner to address some subset of previously defined needs (the needs become the system research objectives). Systems are subsystems of one or more of the various overall waste remediation systems.

The objective of each of these funded development proposals is to advance the technologies of that system and demonstrate its performance to the point that it will be accepted and commercialized by waste remediation contractors. The LSFA system development process advances the level of the higher risk technology components of the system so the private sector willingly takes these proven and demonstrated systems and completes the straightforward commercialization development process.

The advanced technology, being developed and integrated into LSFA systems, is specifically selected to address the needs for safer, faster,

better, and cheaper ways to remediate DOE buried waste. With a given DOE waste site, the technical/legal process for cleanup would specify a particular overall remediation system approach. Then, private sector contractors would select from the "tool box" of available proven technologies to propose, in a competitive bid, their approach to the specified overall system for the particular DOE waste remediation task.

The development of LSFA systems provides suites of advanced technologies available for these contractors to commercialize, increase their options, and make their proposals more competitive. The logic is that by offering these improved capabilities to the private sector, safer, faster, better, and cheaper contractor remediation bids will result. This will result in reduced health and safety risk to workers, the public, and the environment, and greater savings to DOE than was originally invested in LSFA projects.

Integrated Demonstrations

Research, development, and demonstration of LSFA systems are spon-

sored for their contribution to addressing the needs of the various concepts of overall waste remediation systems. The technical objectives of the LSFA systems are derived from the LSFA needs. During testing, the system is evaluated against technology-specific performance objectives and high-level system objectives to assess both individual system performance and impact on the overall system.

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

efforts at Hanford, Oak Ridge, INEL, and Los Alamos.

As LSFA system development approaches the demonstration stage, LSFA combines these systems to conduct integrated demonstrations. The integrated demonstration is a cost-effective method to evaluate the performance of multiple systems acting in concert as in simulated real-life conditions. Additionally, these integrated demonstrations are a subset of an overall remediation system. These demonstrations provide the opportunity to not only evaluate the individual performance of the LSFA systems, but also the performance of the subset the overall remediation system.

LSFA systems evaluations are also strongly influenced from the Comprehensive Environmental Response, Compensation, and Liability Act (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 LSFA systems. In FY-95, LSFA

will continue to work with the U.S. Environmental Protection Agency, Region X, in developing a uniform testing protocol to further enhance acceptance of demonstrated LSFA systems. Published LSFA technology evaluation reports become reference sources for ER/WM decision analyses.

Field testing is done to verify the technical capabilities of the system to ensure that they meet the needs of the customer(s). During the two previous fiscal years (1993 and 1994), BWID developed and performance tested a number of new systems consisting of individual technologies. The overall remediation system that the integrated demonstration of these field tests were modeled after was "Retrieval and Ex Situ Thermal Treatment." For FY-95, the LSFA will be modeled after a combination of the existing BWID remediation options configured as "Hot Spot Retrieval Ex Situ Treatment with Containment and Stabilize."

The systems for each year's integrated demonstrations were selected from the functional areas of site characterization, retrieval, treatment,

stabilization, and containment. Field testing of these systems, as an integrated demonstration, is considered the final development stage prior to technology transfer for commercialization by the private sector.

Technology Transfer

The process by which developed and demonstrated LSFA systems become technology options to the private sector for use in their competitive bids for DOE buried waste remediation is referred to as "technology transfer." Three objectives of technology transfer are integral to 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 LSFA to industry (commercialization).

Technology diffusion is the principal objective and end product of the LSFA program. A strategy has been developed to meet this principal objective. First, 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, 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 (e.g., Cooperative Research and Develop-

ment Agreement, license, 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.

LSFA also works closely with the DOE EM Technology Transfer Network to package and disseminate technology information to industry and end-users. Through the network, LSFA 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 the customer's needs, providing a technology to solve customer problems, and forming strategic action plans to transfer the technology, LSFA is successful in implementing and commercializing demonstrated technology.

TECHNOLOGY ROADMAPS

The purpose of this section is to provide the user of this book with an organized way of accessing the summaries of the various LSFA system writeups. The whole LSFA technology development process focuses on various overall waste remediation options. Therefore, this section will use each of these remediation options as a roadmap for the reader to access information on those LSFA systems that are part of that option.

Figures of each of the overall remediation options along with the names and page number within this book of the relevant LSFA systems are provided for that purpose. For example, if the reader is interested in the overall remediation option of Retrieval and Ex Situ Treatment, the reader should refer to Figure 1 to access information on the LSFA systems that are part of this option. If the reader does not want to use these roadmaps, then she or he will find that the overall organization of the LSFA systems is cataloged by the following sections (same as FY-94):

- Site Characterization
- Waste Characterization
- Retrieval
- Treatment
- Containment.

The figures on the following three pages are the overall remediation roadmaps.

Figure 1. Retrieval and Ex Situ Treatment.

Figure 2. In Situ Stabilization, Treatment, and Monitoring.

Y95 0268

Figure 3. Containment.

Y95 0269

SITE CHARACTERIZATION

Point of Contact

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THERMAL INFRARED IMAGING SYSTEM

Demonstration of this technology was completed in FY-92.

Principal Investigators

- Martin Marietta Corporation
- David E. Shropshire and Reva A. Hyde, INEL

Research Objective

Demonstrate an airborne infrared sensor method to detect and map ordnance and buried 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, IIRG (Infrared Radiation Imaging Gyro) 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 buried waste sites. It could help to locate specific areas of suspected buried 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 tracts 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, and the SL-1 burial pit and trench at the INEL. Imaging was most successful at the Naval Ordnance Disposal Area. Results from this demonstration indicated the system has the potential to detect 6-in. ordnance or shrapnel at depths of 1–2 ft below the surface. Ground surveys are necessary to validate identified anomalies. Multisensors such as electromagnetic, infrared, and gamma

might be operated together on the aerial platform. More information would result from a single survey and data from the multisensors could be merged.

Collaboration/Technology Transfer

In addition to buried waste and ordnance, markets involving underground tanks, pipes, and large objects should provide incentive for collaboration and partnerships in further technology development. 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).

MAGNETIC AND ELECTROMAGNETIC GEOPHYSICAL SURVEYING

Demonstration of this technology was completed in FY-92.

Principal Investigators

- EBASCO Services, Inc.
- David E. Shropshire and Reva A. Hyde, INEL

Research Objective

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

Technology 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 provides 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 revealed broad geological anomalies. 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 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. The results of the aerial surveys can enhance data reduction of existing high resolution ground surveys of the same regions.

Collaboration/Technology Transfer

This research demonstrated a commercialized technology. 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.

RAPID GEOPHYSICAL SURVEYOR

Demonstration of this technology was completed in FY-93.

Principal Investigators

- Glen S. Carpenter, Nick E. Josten, and 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.

Waste Management/ Remediation Need

This technology can provide a viable geophysical survey of buried waste sites such as the INEL Radioactive Waste Management Complex. 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.

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.

Accomplishments

The RGS was successfully demonstrated at the INEL Cold Test Pit and then used to scan buried waste at Pits 7 and 9 at the Radioactive Waste Management Complex and at Los Alamos National Laboratory. Straight-forward 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 collected spatially denser data sets than previously thought possible, thereby providing a much higher resolution picture of the buried waste site. Other geophysical instruments might be incorporated on this platform such as gamma detectors, chemical detectors, and an electromagnetic system. The surveyor was developed for less than \$200,000.

Collaboration/Technology Transfer

Disclosure of this research to private sector interests via technical journals, presentations at technical conferences, and demonstrations have initiated interest in the RGS. A patent has been applied for by the inventors. The inventors have formed a company, Sage Earth Sciences, Inc., to market the RGS technology. The DOE has given an exclusive license to the inventors.

Rapid Geophysical Surveyor
(94-0096-2-5).

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

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. The RCS is a viable technology as demonstrated. However, the RCS needs to be brought up to the level necessary to meet difficult environmental and operational requirements that would be encountered at a real waste site. As the technology matures, its unique features offer great efficiency and cost savings to waste site characterization for extremely hazardous sites.

Collaboration/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 Environmental Protection Agency Superfund sites. International markets also look promising with extensive cleanups in foreign 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).

GROUND PENETRATING RADAR

This technology was initiated in FY-93 and completed in FY-94.

Principal Investigators

- D. K. Parrish and W. M. Roggenthen, South Dakota School of Mines and Technology

Research Objective

Perform a multidiscipline assessment of existing underground radar surveying techniques, particularly as they relate to dielectric properties and attenuation as a function of radar wave frequency and the mineralogy at the INEL.

Technology Description

Ground penetrating radar is a nonintrusive method to determine geophysical characteristics of soils such as that at the INEL Radioactive Waste Management Complex. Underground radar performance enhancement depends on such areas as unique data processing, optimum excitation wave shapes, excitation wave frequency content, excitation signal coupling, and signal processing.

Waste Management/ Remediation Needs

A viable underground radar survey of the Radioactive Waste Management Complex would provide critical data about the waste pits. These

data include 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. Results of this research are transferable to other sites, particularly those sites with high clay content soils.

Accomplishments

The assessment of existing ground penetrating radar performance in soils at the Radioactive Waste Management Complex (mineralogy, dielectric properties and attenuation) and problems with the use of the technology at the INEL have been provided in a report entitled "Factors Affecting Probing Radar at the Radioactive Waste Management Complex Idaho National Engineering Laboratory."

Collaboration/Technology Transfer

No hardware or software was developed for this effort. All information obtained through these studies is contained in the report, which is

an excellent reference for researchers when they develop the operational waste characterization systems for use at the Radioactive Waste Management Complex and elsewhere. The methodology relating underground radar and geophysical properties to potential applications assists those in transferring technology to other DOE and Superfund sites.

Ground penetrating radar survey conducted by South Dakota School of Mines and Technology (93-1 09-1-2).

Ground penetrating radar data of INEL Cold Test Pit.

TENSOR MAGNETIC GRADIOMETER SYSTEM

Technology testing was conducted in FY-94.

Principal Investigators

- D. D. Snyder, RUST Geotech, Inc.
- V. L. Labson, U.S. Geological Survey

Research Objective

Develop and demonstrate site characterization and object location using a tensor magnetic gradiometer applied specifically to DOE buried waste sites.

Technology Description

The tensor magnetic gradiometer system (TMGS) nonintrusively measures the vector magnetic field and the magnetic gradient tensor at a waste site for use in site characterization. The system consists of a four-element array of high-sensitivity triaxial ringcore fluxgate magnetometers and supporting software. The TMGS measures five independent components of magnetic gradient and three components of the 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

The TMGS is a unique technology that is expected to provide significant improvements in interpretation compared with conventional instrumentation and interpretive methods for nonintrusive site characterization. It provides more information about near-surface geology and buried magnetic objects than measurements of a single component of the magnetic field or its gradient. It is intended to provide maps or images of the subsurface distribution in near real time and will be deployed on a wheeled vehicle.

Cost savings are difficult to quantify. However, the use of nonintrusive characterization systems can reduce the potential cost of intrusive sampling and analysis. Sampling and analysis can run \$500 per sample with a complete sampling plan requiring hundreds of samples. A savings of \$20,000 to \$70,000 is possible, not to mention the unestimated savings in worker exposure during sampling.

Accomplishments

The tensor magnetic gradiometer has been modified for mobile application and basic TMGS hardware has been completed. Software for data acquisition, basic data reduction, and elementary interpretation has also been completed.

Collaboration/Technology Transfer

The TMGS 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 TMGS, firms involved in buried waste cleanup, organizations interested in locating buried objects such as mining and oil companies, and Department of Defense contractors locating buried unexploded ordnance provide some of the markets and interest in this concept.

Tensor magnetic gradiometer
(94-493-1-5).

BROADBAND ELECTROMAGNETICS

Technology testing was conducted in FY-94.

Principal Investigators

- H. David MacLean, RUST Geotech, Inc.
- L. Pellerin, U.S. Geological Survey
- M. C. Pfeifer, INEL
- K. H. Lee, Lawrence Berkeley Laboratory
- H. T. Andersen, Hadley & Hollingsworth
- M. Zhdanov, University of Utah

Research Objective

Demonstrate and further develop three-dimensional waste site delineation by broadband electromagnetics.

Technology Description

Conductive waste forms at DOE waste disposal sites can be located and mapped using commercial electromagnetic systems developed for the mineral exploration industry. These systems function by measuring the magnetic and electrical fields induced in conductive objects by a controlled signal from a transmitter. Time domain electromagnetic (TDEM) systems measure the transient signals over a broad time range. Because induced currents of different frequencies or time equivalence flow in different portions of the

conductor, analysis of the broadband response permits location of the conductive objects in a three-dimensional sense and also indicates various portions of the site that contain wastes of different conductor quality.

Most existing commercial TDEM systems are optimized for the detection of large conductors associated with mineral deposits. This project evaluated TDEM systems and analysis methods that are applicable to mapping the small conductive zones associated with waste sites. The advanced analysis methods are available only through individual researchers at academic institutions and government laboratories. They include nonlinear three-dimensional inversion, migration, continuation, and pattern recognition.

Waste Management/Remediation Need

Historical records of the exact location of waste repositories at many DOE waste sites may not be totally reliable because of construction activity over time and the possible corruption or loss of the records. This technology provides a

means of nonintrusively locating buried wastes relative to median survey grids. Knowledge of the precise location of waste pits and of contained waste forms will significantly benefit efforts to characterize and remediate these sites.

Technology Attributes

The broadband electromagnetic analysis technology is expected to provide significant improvement in the interpretation of electromagnetic data compared to existing electromagnetic systems that have been developed specifically for waste site characterization. The method acquires electromagnetic data over a broad time or equivalent frequency range at the same costs as would be incurred by conventional single frequency systems. The advanced analysis methods evaluated through this project are capable of producing three-dimensional maps or images of wastes in near real time.

The use of nonintrusive characterization systems can reduce the potential cost of intrusive sampling and analysis. These activities can cost as much as \$500 per sample, with a complete sampling plan requiring hundreds of samples. However, the

principal cost savings are achieved through the avoidance of spreading of contamination by the sampling process. Savings in worker exposure during sampling activities are also achieved.

Accomplishments

Three-dimensional maps or images of the three waste sites at the INEL Radioactive Waste Management Complex have been produced with the advanced analysis methods mentioned above. An optimal antenna system has been designed and demonstrated. The system is available for immediate use and will be further demonstrated at the burial ground within the Savannah River Site.

Collaboration/Technology Transfer

In addition to DOE facilities at Lawrence Berkeley Laboratory and the INEL, the U.S. Geological Survey, the University of Utah, and Hadley & Hollingsworth, a commercial geophysics practitioner, are joint participants in the project and have demonstrated the above-mentioned analysis methods. The analysis methods used for these demonstrations are of interest to the general

geophysics community, including instrument manufacturers and geophysical contractors. Transfer of the results of this research will be achieved through seminars and peer-reviewed articles in professional journals.

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

Broadband electromagnetic data of INEL Cold Test Pit.

INVERSE SCATTERING GROUND PENETRATING RADAR IMAGING OF BURIED OBJECTS

This technology was lab tested in FY-94.

Principal Investigator

- Steven A. Johnson, TechniScan Inc. (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 evaluates advanced ground penetrating radar imaging methods using inverse scattering techniques. Inverse scattering is an imaging method for computing quantitative images of the physical properties of bodies by adjusting a model of these physical properties so that the predicted scattered field from this body matches most closely the measured scattered field.

Waste Management/ Remediation Need

This technology could be applied to characterizing buried waste at the INEL Radioactive Waste Management Complex and other DOE sites. By identifying buried objects by shape, orientation, dielectric constant, and location, remediation options can be selected in a cost-efficient manner.

Technology Attributes

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

Accomplishments

TechniScan completed the development of a prototype three-dimensional scanner during FY-94. A series of laboratory inverse scattering experiments were performed to produce images of known objects in air and buried in high purity sand and INEL soil. Based on these experiments, TechniScan has developed a body of knowledge for future research activities including:

- The degree of image quality is directly related to the degree of accuracy in modeling the electromagnetic fields of the antennas
- General methods for calibrating antennas
- A procedure for calibrating ridged horn antennas
- A theory for using soil coupled antennas for improving imaging.

Collaboration/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 buried waste characterization and remediation projects. Companies interested in locating buried objects such as mining and oil interests and Department of Defense contractors locating buried unexploded ordnance also might use the technology.

Tomographic microwave scanner.

Scale-model of ground penetrating radar scanner.

NONINTRUSIVE CHARACTERIZATION AND SENSING OF BURIED OBJECTS

Work on this technology was completed in FY-94.

Principal Investigators

- Pieter Hoekstra and Ray Lahti, Coleman Research Corporation

Research Objective

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 high density data using commercially available instruments and sensors (magnetic, frequency domain electromagnetics, time domain electromagnetics, and ground penetrating radar). 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 obtained survey data over the INEL Cold Test Pit on magnetic field, conductivity, and ground penetrating radar. The time domain electromagnetics system is tested specifically for detecting shallow buried metallic targets. Advanced

techniques then 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 Cold Test Pit.

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.

Technology Attributes

This technology uses existing commercial instrumentation but is unique in several respects: (a) the variety of sensors that are used, (b) the advanced methods of fusing data from multiple survey instruments together, (c) the displaying of coherent results with three-dimensional plots of the survey site, and (d) the use on a characterized buried waste site that simulates many DOE sites.

Cost savings that have not been quantified as savings are site specific. Savings are realized when the technology can identify and locate subsurface objects with increased confidence and accuracy. This increased accuracy reduces waste excavation and treatment costs.

This technology uses existing commercial instrumentation but is unique in several respects:

- The variety of sensors
- 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.

Accomplishments

Data fusion techniques were limited because favorable results occurred only with the electromagnetic sensors, frequency domain electromagnetics, and time domain electromagnetics. The ground penetrating radar system was not effective in the clay soil of the Cold Test Pit or Idaho Chemical Processing

Plant. However, these results reinforce the importance of using multiple sensors in a site survey for characterization. The magnetic sensor performance has been improved throughout the study. Advanced methods of displaying an overall interpretation of sensor data were developed.

Collaboration/Technology Transfer

This research was conducted by the private sector (Coleman Research Corporation) through a Program Research Development Agreement. The results of the research were presented 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 (93-375-1-9).

Profile plots and contour maps obtained from TDEM metal detector.

DIGFACE CHARACTERIZATION

Full-scale field demonstration will be conducted in FY-95.

Principal Investigators

- Nick E. Josten, Kevin M. Croft, and 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 digface during excavation.

Technology Description

The digface characterization project is an integrated demonstration of multiple sensors that can be used as part of a retrieval effort. The digface characterization technology will allow continuous and continually improving monitoring and characterization of the site being remediated. The digface 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 digface 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 digface 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.

Multiple sensors characterize the digface during progressive soil removal. The sensors measure geophysical, radiological, and chemical properties. Development of

an automatic deployment capability and development of refined data interpretation techniques support rapid target identifications and are powerful features of this technology.

Accomplishments

Three prototype sensors were developed for digface application: a gamma spectrometer, a dielectric permittivity sensor, and a focused electromagnetic induction sensor. Laboratory data for the dielectric permittivity and gamma spectrometer sensors indicate that both are feasible candidates for digface application.

The pilot-scale testing using a soilbox to simulate the digface for automated deployment of sensors on a robotic gantry crane system is complete. The field testing of a prototype digface characterization system used a test trench at the INEL Cold Test Pit. The system's multiple sensors were deployed with a manual nonmetallic gantry designed and constructed to support obtaining dense data sets in a noninterfering environment.

Data were obtained for several commercial sensors (magnetometer,

electromagnetic sensor, chemical sensor) deployed over simulated targets in multiple passes as soil layers are progressively removed. The resolution capabilities of the sensors have been evaluated. They are able to support development of real-time interpretation of targets needed for digface application.

The prototype dielectric permittivity sensor, gamma spectrometer/chemical assay system, and test sensors along with the gantry crane and Schilling arm were built. The integrated system is now ready for complete full-scale demonstration.

Collaboration/Technology Transfer

The successful completion of the demonstration resulted 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 (INEL Buried Waste Robotics Program), and mining interests (Colorado School of Mines and U.S. Geological Survey) 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.

Other DOE and Department of Defense sites have been contacted to identify an agency that is planning an actual remedial or removal action for a radiologically and chemically contaminated site. Their collaboration with the INEL will be sought to use the digface technology in the remediation activity.

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.

The digface characterization system designed to scan waste pit to provide data on location and composition of the waste was successfully demonstrated at the INEL Cold Test Pit (93-901-2-14).

Pilot-scale robotic deployment of digface sensors using a soilbox to simulate the digface (93-683-1-2).

VIRTUAL ENVIRONMENT VISUALIZATION OF BURIED WASTE

Technology development continues through FY-95.

Principal Investigators

- Tom K. Larson and L. Eric Greenwade, INEL

Research Objective

Investigate the issues, requirements, and feasibility of developing a computer-generated virtual environment of buried waste artifacts for use in the remediation of 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 parallel 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 is a key part 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 also supports 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 assists in developing a remediation strategy. Improved imaging and manipulation techniques increase the efficiency and safety of remediation operations.

Accomplishments

Three different rapid prototype environments were constructed using the INEL Cold Test Pit as a basis. Included were a walkthrough

of the Characterization Cell, a visual database of the Characterization Cell, and an example three-dimensional data display.

A hardware system was designed that integrates different functionality into a single overall platform. The prototype system has access to data, database information, and analysis tools that are of interest or use to buried waste characterization activities.

An Automatic Target Recognition (ATR) system was evaluated for use in assisting in interpretation of sensor data obtained during the digface characterization process. The ATR system performance was good for the data interpretation application. Although there were some errors in distinguishing boxes from barrels, the system was capable of distinguishing target objects from background soil.

Collaboration/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 remediation and other applications.

Computer-generated virtual
environment of buried waste.

IMAGING INFRARED INTERFEROMETER

Work on this technology continues in FY-95.

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. A prototype infrared interferometer will be field demonstrated in FY-95.

Technology Description

To provide real-time imaging, a standoff system is being developed using a real-time passive infrared imaging system.

The imaging interferometer consists of a mercury cadmium telluride (MCT) infrared detector coupled to a Physical Sciences proprietary interferometer and a scan camera. The spectral region of 10.2–14.5 μm is passively sampled and a wavelength selective image constructed using a PC-based interface. Volatile organic compound plume constituents are identified using an automated reference spectra searching routine. The system will be enhanced specifically to monitor volatiles and offgas

contaminants from a waste remediation site.

A computer controls the mirror spacings, alignment, and processing of the infrared images. This approach allows multispectral imaging of a 15–40 degree field of view. The system will be enhanced specifically to monitor volatiles and offgas contaminants from a waste remediation site.

Waste Management/ Remediation Need

This technology enables 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 are:

- 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.

Because this is a new technology, no baseline exists to compare costs savings. Cost savings will be realized by the technology's ability to provide real-time volatile organic compound (VOC) characterization without manually or robotically deploying sensors to the source.

Accomplishments

Target gases were identified that the system would respond to and that might be present in buried waste. Calculations of these gases as to sensitivity in typical atmospheric conditions have been performed. At a distance of 10–20 meters, VOCs can be detected at 10-ppm concentration in air within the normal operating spectral range of 10.2–14.5 microns. An emission rate of 1 g/min was assumed for this modeling program. The field demonstration will involve the unearthing of isopropanol (rubbing alcohol) placed within the soil/waste. The VOC plume will allow detection limits to be established and quantification range for identifying organics to be determined during actual remediation type operations with all the other factors present such as exhaust fumes, dust, and engine heat.

Collaboration/Technology Transfer

Physical Sciences, the private-sector partner, is the primary avenue for technology transfer and commercialization. Industrial, U.S. Environmental Protection Agency, and Department of Defense waste sites may have use for the technology. Nonwaste interests (e.g., mining and chemical processing) also may be markets for remote real-time infrared imaging.

The imaging infrared interferometer is used to detect volatile organic contaminants (VOCs).

HIGH RESOLUTION IMAGING USING HOLOGRAPHIC IMPULSE RADAR ARRAY

This technology was initiated in FY-94 and will be demonstrated in FY-95.

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 generates real-time, three-dimensional images of shallow buried waste in low conductivity soils (i.e., dry sand). Existing holographic array imaging software will be modified for demonstration at Pacific Northwest Laboratory and the INEL in FY-95.

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 2.5–7 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. 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, the INEL, and Brookhaven National Laboratory.

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.

Cost savings have not been quantified. However, the use of nonintrusive characterization systems can reduce the potential costs of intrusive sampling and analysis.

Accomplishments

The tapered slot antenna bistatic array and a mounting fixture for an array vehicle have been made. Successful demonstration of a 5-GHz prototype ultra-wide band GPH was made on specific targets in a controlled environment composed of the INEL and Hanford soils. Modifications for field use have been made.

Collaboration/Technology Transfer

The opportunity exists for private-sector involvement in the development of this technology. GPH has applications beyond buried waste remediation. Various companies interested in locating buried objects such as mining and oil interests and Department of Defense contractors locating buried unexploded ordnance provide some of the markets and interest in this concept. The interaction of the radar hardware and software and implementation at 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.

Ground-penetrating holographic radar imaging system being tested.

Through use of a ground-penetrating holographic radar system, the image of a drum lid was created in INEL soil.

VERY EARLY-TIME ELECTROMAGNETIC SYSTEM

Work on this technology continues through FY-95.

Principal Investigators

- Louise Pellerin and Victor F. Labson, U.S. Geological Survey
- Mary C. Pfeifer, INEL

Research Objective

Design a high resolution electromagnetic imaging system for shallow environmental problems (less than 10 meters) such as buried waste sites. Specifically, this system is being developed for use at waste sites where traditional electromagnetic equipment and interpretation techniques do not produce adequate results. FY-95 research focuses on completing three-dimensional computer forward modeling, physical modeling, and field testing of instrumentation.

Technology Description

The very early-time electromagnetic (VETEM) system collects and interprets data from the shallow subsurface. This instrument operates in the region of the electromagnetic spectrum between low frequency electromagnetic induction and ground penetrating radar frequencies. This region of operation allows the system to be used at sites where ground penetrating radar has little

success. Physical and numeric models being developed 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 Radioactive Waste Management Complex and other DOE sites. Specifically, it could contribute to identifying buried objects by shape, orientation, and location.

Technology Attributes

The resulting system, along with interpretation and imaging software, enhances resolution of the shallow subsurface. Additionally, this system will operate at sites where the physical properties of the soils make

high resolution ground penetrating radar difficult.

Cost savings can be estimated based on sampling and analysis costs of \$300 a sample. If the use of nonintrusive characterization systems can reduce the intrusive sampling and analysis load by 75% of the samples, a typical sampling plan requiring 1,000 samples can be limited to 250 at a cost savings of \$225,000 per site and a great savings in worker exposure.

Accomplishments

One-dimensional numerical modeling algorithms were developed and tested and are being used in physical analysis of the buried waste problem, interpretation of field data, and systems analysis devoted to instrument design. An optimal system was designed using physical modeling. A prototype transmitter loop has been fabricated. The existing instrumentation and interpretation systems were field tested at the INEL Cold Test Pit. A one-dimensional interpretation of the high frequency sounder data gave very realistic estimates of the thickness, dielectric permittivity, and electrical conductivity properties of

the cap covering the Cold Test Pit waste.

An upgraded prototype time-domain electromagnetic instrument and the second generation frequency-domain high frequency sounder were fabricated and are being field tested. The one-dimensional code, with a graphical user interface, will be transferred to industry at the close of the project. These systems will acquire data in a tenth of the time required by the first generation instruments.

Collaboration/Technology Transfer

Many outside universities, companies, and national labs are collaborating in developing this technology. The participants include the University of California-Berkeley, University of Arizona, University of Utah, Colorado School of Mines, RUST Geotech, Inc., Lawrence Berkeley Laboratory, and Sandia National Laboratories. 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 electromagnetics, firms involved in buried waste cleanup, companies interested in locating buried objects such as mining and oil interests, and Department of Defense contractors locating buried unexploded ordnance provide some of the markets and interest in this concept.

VETEM high-frequency sounder
(94-602-1-2).

PLATFORMS FOR ELECTROMAGNETIC AND MAGNETIC SENSORS

The evaluation report was published in FY-95.

Principal Investigators

- Mary C. Pfeifer, INEL
- Louise Pellerin and 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

Radioactive Waste Management Complex and other DOE sites. Specifically, it could contribute to identifying buried objects by shape, orientation, and location.

Technology Attributes

Evaluation criteria included cost of deployment, ease of use, availability, and suitability to buried waste problems. This aided in determining which type of platform best fits the characterization system requirements of future buried waste projects.

Accomplishments

These studies evaluated electromagnetic and magnetic sensor platforms. Preliminary sensor platform evaluation criteria were established based on operational and sensor constraints. These technologies were evaluated against these criteria. The completed final report, entitled "Evaluation of Platforms for Electromagnetic Geophysical Sensors in Site Characterization," has been distributed as a USGS open file report.

Collaboration/Technology Transfer

At the completion of this study, the final report was distributed to the

DOE Office of Technology Development so that it may be used to evaluate proposals received for consideration for funding in FY-96. 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.

WASTE CHARACTERIZATION

Point of Contact

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RAPID TRANSURANIC MONITORING LABORATORY

Demonstration of this technology was completed in FY-94.

Principal Investigators

- Charles V. McIsaac, Claude W. Sill, and Robert J. Gehrke, INEL

Research Objective

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

Technology Description

The RTML is housed in two trailers, 8 x 24 ft and 8 x 48 ft in size. Both are fully transportable for location on a remediation field site. The smaller trailer houses a sample preparation laboratory. The larger trailer contains one computer system that controls and displays spectral data from four alpha continuous air monitors, two Ordela large-area ionization chamber alpha spectrometers, one thin-window gamma ray spectrometer and automatic sample changer, one VAX 4000 Model 100 computer, and computer terminals and two printers used to display and generate reports of analysis results. During FY-94, several beta systems were acquired/constructed for evaluation purposes.

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 ionization alpha 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 1-5 pCi/g (gamma). Simultaneously, the alpha continuous air monitors can analyze air quality continuously at 1 DAC-hr.

Waste Management/Remediation Need

The RTML is appropriate for any situation where there is a major problem with transuranic contamination that requires mitigation. The RTML can quickly evaluate situations and allow rapid remediation action to be performed that prevents a situation from growing further out of control.

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.

The unit can process over 100 samples per day of soils, filters, and smears in a field setting, compared to radiochemists at a fixed laboratory who can analyze only a few samples per day with conventional radiochemistry techniques.

Accomplishments

The system was successfully demonstrated in a field setting at the Cold Test Pit at the INEL Radioactive Waste Management Complex during the summer of 1993. The INEL Environmental Restoration Program used the system as a screening tool during the sitewide soil-sampling effort in FY-94.

Collaboration/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 has enhanced 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 and several other DOE sites are looking at using the system. Draft agreements for transfer of the RTML to Thermo Analytical, Inc., are being prepared and reviewed.

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METAL/ISOTOPE ANALYSES BY ELECTROTHERMAL/ PLASMA AND DIODE LASER SPECTROMETRY

The technology was demonstrated in the laboratory and a field demonstration was initiated in FY-94.

Principal Investigators

- Stephan Weeks, Robert Lipert, and David Baldwin, Ames Laboratory

Research Objective

Provide decisionmaking, self-verifying, quantitative measurements for metals and isotopes on Target Analyte Lists at site characterization, remediation, and closure activities. Develop methods for the variety of sample types.

Technology Description

The technology performs analyses on elements (e.g., RCRA metals, actinides, and rare earths) and their isotopes (e.g., PU-238 and U-238) by optical spectrometric techniques in a mobile field laboratory for environmental site support. A variety of sample types (e.g., soils, air particulates, sediments) can be analyzed for their contaminant concentrations relative to the regulatory action levels.

Microliter amounts of samples in liquid or slurry form are electrothermally vaporized using technology that has been developed over two decades in Atomic Absorption

Spectrometry (AAS). In the simplest form, the instrumentation can be operated to perform EPA-approved AAS methods. Gas-phase samples also may be introduced, for example, by conventional hydride generation methods. Either conventional hollow cathode lamps or diode lasers may be used to interrogate the atoms in the atom source to provide quantitative determinations. Diode lasers allow high resolution spectrometric measurements for quantitative isotope analysis.

Radio frequency (RF) plasma excitation can minimize interferences and increase analyte atom densities, thereby lowering the amount capable of being detected (typically in the ppb or pg range). This RF excitation creates a plasma similar to that used in ICP-AES, but the plasma is created directly in the electrothermal (typically, graphite) furnace. The use of solid state array detectors provides multi-element, multi-line, and simultaneous emission measurements. In this manner the matrix can be monitored and the analyst can be altered to potential interferences. This is crucial for accurate determinations in unknown environmental or

waste materials. These emission measurements can be performed simultaneously with the absorption measurements.

Diode lasers allow analytical measurements of radioactive isotopes to be made in the field. Laser absorption, optogalvanic, and fluorescence techniques provide quantitative analyses on microsamples with no isobaric interference and minimal sample preparation (no lengthy separations).

Data validation is accomplished immediately because simultaneous multiple measurements are made by absorption, emission, optogalvanic, or fluorescence spectrometric techniques. Statistical methods would allow increased accuracy by cross validation of the measurement, reducing interferences and increasing the level of confidence in the reported contaminant concentration levels.

Waste Management/ Remediation Need

This technology complements the radiation measurement techniques used by the Rapid Transuranic Monitoring Laboratory. It provides

onsite capability for quickly assessing radioactive and hazardous contamination problems associated with buried waste remediation. During mixed waste handling operations, such as buried transuranic waste retrieval, greater turnaround in sample analyses can determine the degree of control of contamination spread.

Technology Attributes

Highly sensitive quantitative measurements of radioactive and hazardous contaminants can be made in an onsite field laboratory to provide rapid response for characterization, remediation, and closure needs. The technique requires minimal sample amounts (micrograms), makes multiple simultaneous quantitative measurements on radioactive isotopes and hazardous metals, minimizes spectroscopic interferences, eliminates isobaric interferences, provides detection capabilities typically at the picogram level, and provides managers and regulators with decisionmaking data.

Accomplishments

The system was demonstrated in the laboratory and a fixed laboratory field demonstration was begun. The

Metal/isotope analyses by electrothermal/plasma and diode laser spectrometry.

DLS-FANES prototype instrument, sample introduction alternatives, detector enhancements, and analytical methods were developed.

Collaboration/Technology Transfer

The technology has been disclosed through professional presentations at conferences and in written articles. Cooperative interaction with the analytical furnace/plasma manufacturer has led to modification of their product to improve the analytical measurement capabilities and performance. This manufacturer has also indicated a willingness to actively support field demonstrations. Transfer of the laser spectrometric isotope measurement methods is being made through professional journal articles and conferences. Information being made available on the Internet and site demonstration will ensure transfer of this technology to the private-sector contractors that may be performing waste site remediations. The system could be used during retrieval actions to verify the presence/absence of hazardous materials and actinides in soils prior to the return of the (treated) soils.

WASTE ASSAY MEASUREMENT INTEGRATION SYSTEM

Work on this technology continues in FY-95.

Principal Investigators

- Timothy J. Roney, INEL
- Idaho State University

Research Objective

Develop and demonstrate improved waste assay capability through the integration of multiple information sources including multiple measurements and prior knowledge. Incorporate intelligent processing methods with expert systems and conventional analysis techniques. Develop the methods to access and visualize all relevant data supporting an individual container. FY-95 objectives are to demonstrate a prototype data visualization workstation using real nondestructive evaluation/nondestructive analysis data from drums stored at the INEL Radioactive Waste Management Complex (RWMC) and confirm the benefits of using neural networks for data processing.

Technology Description

The Waste Assay Measurement Integration System (WAMIS) will consist of software that performs several functions, all from a single workstation, including access to all relevant data on a drum, visualization of the data, several modes of simultaneous processing to enhance

drum characterization, and displays of results to a variety of possible end-users including operators, physicists, regulators, and receiving personnel at disposal sites. Data-processing methods will include a combination of conventional approaches, expert systems, and artificial intelligent processing.

As a test case in FY-95, data from real drums at RWMC will be used to demonstrate the capabilities of the system. The measurement capability at RWMC includes real-time radiography, gamma spectroscopy, and an active and passive neutron measurement. When WAMIS is demonstrated in FY-96, it will integrate data from three other NDE/NDA systems: Digital Radiography and Computed Tomography (DRCT), Combined Thermal and Epithermal Neutron (CTEN), and Active and Passive Computed Tomography (A&PCT).

Waste Management/ Remediation Need

The WAMIS technology would directly apply to the remediation of buried waste sites when the waste is containerized if a retrieve and treat option is implemented. Retrieved

waste would need to be assayed and packaged to ship to an interim storage or treatment facility meeting U.S. Department of Transportation shipping limitations and various receiver facilities' Waste Acceptance Criteria. Prior to treatment, another assay would likely be performed and at posttreatment an assay would be performed.

Technology Attributes

The key attribute of WAMIS will be the ability to optimize use of all available data on a subject container. Data-processing methods successful in other applications will be transformed and improved for the waste assay application. Cost savings also are important. DOE has estimated that if all of the waste drums had to be opened for characterization and certification, an immense cost would be incurred. With the number of drums being in the hundreds of thousands, the savings may be millions of dollars. This is in addition to worker safety concerns and any associated dollars for preventing excess exposure.

Accomplishments

This project is an outgrowth of an older project known as the Radio-

logical and Hazardous Material Measurement System (RHMMMS). In prior years, several measurement systems were tested and determined to be critical to the multiple measurement process. These methods included gamma ray spectroscopy and passive and active neutron. The project was redirected in FY-94 and renamed in FY-95 to WAMIS. The redirection was to develop the software needed for integration and to develop the plan for the FY-96 demonstration that will bring DRCT, CTEN, and A&PCT together. In FY-94 both of these processes were initiated. The initial software demonstration will be done with existing data from existing systems. Also in FY-94, a proof-of-principle experiment using neural networks to process real neutron assay data was successfully performed.

Collaboration/Technology Transfer

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.

The data integration process.

Data visualization workstation leads to integrated results.

REAL TIME MONITORING OF TRANSURANIC CONTAMINATED DUST

Work on this technology continues in FY-95.

Principal Investigator

- Judy K. Partin, INEL

Research Objective

Develop and demonstrate a real time, in situ instrument based on optical techniques for monitoring transuranic-contaminated dust. The prototype instrument is being developed for deployment to the field in FY-95.

Technology Description

A real time dust monitor (RTDM) monitors for transuranic-contaminated dust. The monitor has a sample pump that draws air samples from the digface of a retrieval area through the monitor chamber. Laser-induced breakdown spectroscopy provides some identification of the predominant elements on the dust particles. From this particle scattering the mean particle size and number density can be determined.

Waste Management/ Remediation Need

The RTDM system is appropriate for any situation where there is a major problem with transuranic contamination that requires mitigation. The RTDM can quickly evaluate situations and allow rapid remediation action

to be performed, preventing a situation from growing further out of control.

Technology Attributes

The real time monitoring aspects of this system 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 continuous air monitor, giving complementary information to the air monitor for alpha determination with measurements to TRU such as particle density. High alpha activity but low mean density can correct for interfering background radon alpha emissions. It also uses laser-induced breakdown spectroscopy strength for detection of many hazardous heavy metals that have strong emission in the visible and ultraviolet regions.

At this time analyses of potential airborne contamination are typically performed by collecting particles over time in a filter and subsequently estimating particle density off line. Depending on the level of accuracy required, this process requires several minutes to half an hour. If the particle density is subject to rapid

fluctuations, off-line monitoring may be inadequate. The proposed system's ability to perform real time detection is a significant advantage in some applications. There are presently no commercially available real time monitors for transuranic-contaminated dust.

There are not any existing technologies that the RTDM can compare to in the area of cost savings. The only comparison that can be made is with the continuous air monitor devices, which require a sample to be accumulated on a filter and then counted for 15–30 minutes to detect low alpha emissions levels while the RTDM operates continuously. Based on a sampling and chemical analyses cost of hundreds of dollars per sample, this device should be very cost effective on that basis alone.

It is estimated that major transuranic waste remediation activities may cost \$1 million per day to operate. Assuming a 10-hour shift, these costs are on the order of \$100,000 per hour. If the operation is shut down to evaluate the radiological hazards or control contamination for 2 hours per day, the associated costs are

\$20,000. It is anticipated that the RTDM could avoid much of this cost by providing real time analyses to the operators.

Accomplishments

Laboratory testing was conducted at the INEL Test Reactor Area using plutonium-contaminated soil or lead-contaminated dust spiked at low ppm levels. The dust is aerosolized and drawn through the RTDM. The instrument was able to detect micron-size particles, in the respirable range in air with a ppm concentrations of the metal (plutonium or lead) in the soil. The concentration of the dust in air used covered a wide range though the dustiness in the field is to be maintained at room concentrations.

Collaboration/Technology Transfer

The primary private customers for this technology are commercial nuclear reactors during decommissioning and decontamination phases of operation. However, the technology also may 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 industry for commercialization. In addition, an opportunity presently exists for a government/industry partnership to promote the development and marketability of this technology.

Laboratory prototype instrumentation for real time monitoring of transuranic contaminated dust (94-1152-1-1).

Schematic of real time transuranic contaminated dust monitor.

DIGITAL RADIOGRAPHY AND COMPUTED TOMOGRAPHY OF WASTE DRUMS

Work on this technology continues in FY-95.

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 and computed tomography (DRCT) of waste packages, with emphasis on 55-gallon waste disposal drums. The FY-95 objective is to characterize the scanner's linear and area detection arrays for drum inspection, develop a high energy source for use on high-density drums, and demonstrate the system on a small number of low-level waste drums.

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. A higher throughput can be achieved by further enhancing the detection system to an area-type detector versus a linear array. A high energy x-ray source will be installed for interrogation of high density drums.

Waste Management/ Remediation Need

DRCT applies directly to the remediation of buried waste sites when the option of retrieve and treat is implemented. Assay and characterization are needed at pretreatment, post-treatment, and disposal. Retrieved containers must be characterized prior to any further treatment and shipment to either an interim storage or treatment facility.

DOE has estimated that if all of the waste drums were required to be opened, the cost would be in the tens of millions of dollars, with the number of drums being in the hundreds of thousands. When DRCT is combined with other nondestructive systems, cost savings in the millions of dollars is estimated in addition to the worker safety issue and any associated dollars for preventing excess exposure.

Technology Attributes

DRCT offers a unique capability to spatially characterize containers of waste as part of the assay process and provides quantitative information where only qualitative information has been available previously. DRCT can evaluate waste drums to

allow for certification to meet Department of Transportation shipping limitations and various receipt facilities' Waste Acceptance Criteria. The technology supports visual drum inspection like the present real time radiography in use at certification facilities but with greater accuracy and speed.

Accomplishments

The x-ray scanner refurbishment has been completed and the scanner has been installed at Idaho State University. The new area detector is completed and is undergoing testing. The upgraded DRCT's performance, particularly the high throughput for the DRCT system, is being demonstrated at the INEL.

Collaboration/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.

Digital radiography and computed tomography using linear and area detectors.

DRCT scanner operating in area detection mode (95-85-1-4).

COMBINED THERMAL/EPITHERMAL NEUTRON WASTE ASSAY

This technology was initiated in late FY-93 and will be field tested in FY-96.

Principal Investigators

- Kenneth Coop and Robert Estep, Los Alamos National Laboratory

Research Objective

Develop a system to assay transuranic/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-dieaway 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 such as the contents of waste drums with both thermal and epithermal neutrons. This is achieved partly by the addition of 4-He detectors, which have a faster response than 3-He 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 supports 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 posttreatment assay of the final packaged waste. Waste drums would directly be evaluated for certification to meet Department of Transportation shipping limitations and various receipt facilities' Waste Acceptance Criteria.

Technology Attributes

The CTEN will allow all of the capabilities of present commercial neutron assay systems with the added capability to evaluate for larger pieces of transuranic material. The technology minimizes the effects of self-shielding by lumps of fissile material to provide more accurate and repeatable assay of waste drums.

This system will incorporate techniques to determine if the waste matrix and fissile material are uniformly distributed. Transuranics have the capability to absorb their own radiation, causing errors when evaluating waste drums that contain large quantities of nonuniformly distributed transuranic material. The assay will be much closer to the actual amount residing in the drum.

Accomplishments

The basic fabrication of the CTEN instrument is complete. The Monte Carlo studies, design drawings, and first version of the system software are complete. Current work focuses on completing algorithm development, data analysis, and system

evaluation to complete the entire system to begin characterization and calibration.

Collaboration/Technology Transfer

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. A Cooperative Research and Development Agreement is being pursued with a commercial company to support software development.

Conceptual drawing of Combined
Thermal/Epithermal Neutron (CTEN)
method.

ACTIVE AND PASSIVE COMPUTED TOMOGRAPHY WASTE ASSAY OF RADIOACTIVE WASTE

Work on this technology continues in FY-95.

Principal Investigators

- Harry E. Martz, Jr., Lawrence Livermore National Laboratory
- University of California San Francisco Medical School
- Bio-Imaging Research, Inc.

Research Objective

Evaluate an active and passive computed tomography (A&P CT) system on low-level radioactive waste and transuranic waste contained in 55-gallon drums.

Technology Description

A&P CT uses a high purity germanium (HPGe) detector for nondestructive assay of gamma-emitting nuclides in sludge, combustibles, and metal matrices within a 55-gallon drum. Assay is necessary for determining radiological content of stored wastes to meet shipping and storage requirements. Included are tasks such as preassay and postassay of retrieved treated waste and residues, meeting Department of Transportation shipping requirements, meeting Resource Conservation and Recovery Act (RCRA) low-level mixed waste disposal regulations, and determining those wastes for below regulatory concern, low-

level radioactive waste disposition, and transuranic waste disposition.

The measurement of fissile elements such as U-235 and Pu-239 is the most critical feature of the system. The system must optimize four critical features: (1) spatial resolution, (2) energy resolution, (3) contrast sensitivity, and (4) total data acquisition time. These parameters are governed by optimum transmission source strengths as a function of density, proper transmission source, proper detector collimation sizes and lengths, and proper balancing of waste assay speed, accuracy, and cost.

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 1-HPGe detector A&P CT drum scanner will:

- Differentiate transuranic from low-level radioactive waste, substantially decreasing shipments to the Waste Isolation Pilot Plant.
- Differentiate low-level radioactive waste from below regulatory concern waste, substantially decreasing shipments to the few low-level radioactive waste repositories that exist.
- Enable DOE to meet potentially more stringent transportation regulations for low-level radioactive waste and low-level mixed waste.
- Give 10–100 times lower minimum detection limit (MDL) for nondestructive drum waste assay than currently available segmented gamma spectrometry, 10 mg MDL for Pu-239 compared to 1,000 mg.
- Decrease assay time with the higher detection limits with multiple detector from 50 minutes to 30 minutes per drum.

DOE has calculated that the cost to open the hundreds of thousands of waste drums is millions of dollars. This is in addition to the worker safety issue with associated costs for preventing excess exposure and the contamination control costs.

Accomplishments

The A&P CT scanner has been used to scan and analyze drums of mock waste. MDLs have been determined from standards and mathematically through optimizing performance parameters. Detailed A&P CT scans of well-characterized drummed waste have been obtained. Demonstration, test, and evaluation (DT&E) scans of additional real waste drums using the Waste Inspection Tomography mobile trailer are scheduled for 1995.

The A&P CT scanner has been developed to the state of system checkout and performance optimization. This work has been accelerated due to the interface with the DOE-sponsored Waste Inspection Tomography system.

Collaboration/Technology Transfer

Technology transfer is under way with the private partner, Bio-Imaging Research, through development of Waste Inspection Tomography 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. Demonstration 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.

Schematic drawing of the A&P CT system.

Coupling multi-energy A&P CT data yield more accurate waste data characterization.

EXCAVATED WASTE ASSAY

Work on this technology continues in FY-95.

Principal Investigator

- Timothy J. Roney, INEL

Research Objective

Develop an assay system for retrieved buried waste and posttreatment waste using a set of nondestructive assay and nondestructive evaluation (NDA/NDE) techniques including radiography, gamma and neutron screens, and gamma spectroscopy. The FY-95 goal is to complete construction of the system and demonstrate on packages of benign soil spiked with sealed transuranic sources.

Technology Description

The system measurements are 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 transuranic contamination. A passive neutron measurement system for spontaneous fission events is the fourth subsystem.

Waste Management/ Remediation Need

Retrieved waste might be assayed immediately as it is removed from the digface, before packaging prior to shipment to an interim storage or treatment facility, prior to treatment, and after treatment prior to disposal. The system will provide information about whether the waste requires treatment and the appropriate storage or disposal location. Segregation of the material removed from the digface allows removal of nonradioactive and low-level radioactive waste from the treatment waste stream, reducing treatment costs. The system can confirm that the treated stream meets radiological requirements for disposal.

Technology Attributes

The principal attributes offered by this technology are improved accuracy, confidence in estimates, and assay of entire pretreated (sifted or ground) waste streams. The final disposition of waste being evaluated can be more easily determined. Waste can be treated appropriately, saving unnecessary treatment and

handling and associated costs. If this assay is not performed, all waste removed from a removal digface would have to be considered waste that required treatment. Cost savings of 400% are estimated based on estimated decrease in waste volume needing treatment. Further savings will be realized with a reduced volume of waste classified as transuranic, reduced waste handling, and reduced disposal costs.

Accomplishments

A prototype system with detection to less than 100 nCi/g using gamma ray spectroscopy has been successfully demonstrated. Lowering this detection to less than 10 nCi/g using gamma ray analysis is being studied. Another system enhancement being considered is incorporation of passive neutron interrogation to improve fissile mass estimates. The system will be demonstrated during the FY-95 buried waste integrated demonstration.

Collaboration/Technology Transfer

This technology is planned to support the INEL Environmental

Restoration Program. Opportunities exist for private-sector involvement in both development and commercialization of this technology. Other nuclear institutions that may aid in further research or be interested in the testing system particularly for their waste stream monitoring include nuclear power plants, DOE sites, countries such as Canada, 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.

The excavated waste assay system.

RETRIEVAL

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CRYOFRACTURE

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, and aerosol containers. The method was adapted and demonstrated as a pretreatment, size-reduction step in processing transuranic 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 Environmental Protection Agency Superfund sites are candidates for such containerized waste treatment.

Technology Attributes

- 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 transuranic waste containers. It was successfully adapted to drum and box-shape containerized, metal, sludge, asphalt, concrete, and waste. The research proved the principle of size reducing containerized waste after cryogenic cooling and reduced containerized waste volumes up to 47%; fractured 90% of the material to less than 6 in. in size. About 0.2–1.3 ft³ liquid nitrogen (LN₂) per cubic foot of frozen debris fractured was required, depending on the type of waste and container.

It is estimated to cost 40% more to build and two to three 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.

Collaboration/Technology Transfer

Further research is needed to expedite the process to conserve LN₂. The drilling of holes or other-

wise 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.

The system already has 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. The project was presented at the Waste Management 92 Conference in a report entitled "Cryofracture as a Tool for Preprocessing Retrieved Buried Wastes."

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 10–12 ft in length, were driven into three areas of the test pit's 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 Environmental Protection Agency 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:

- Demonstrated remote retrieval of simulated buried transuranic waste
- Demonstrated containment of contaminant spread over nonfrozen retrieval
- Required 6–7 ft³ of LN₂ per cubic foot of frozen soil and debris retrieved.

Collaboration/Technology Transfer

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.

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.

The work was presented in a report at the Waste Management 93 Conference entitled "Buried Transuranic Retrieval Using Cryogenic Techniques."

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

Remotely operated gantry deployed
retrieval equipment (92-334-2-32).

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 carrier 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 hazard-

ous environments. Coupling this type of equipment with the type of remote operation technology that was demonstrated on the Remote Excavation System 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.

Collaboration/Technology Transfer

This class of technology is already in the commercial sector. The remotization of this equipment offers opportunities for collaborative efforts. The results were presented in a report entitled "Retrieval of Buried Waste Using Conventional Equipment" at the Waste Management 94 Conference and as an INEL report.

Full-scale retrieval demonstration at Caterpillar Cold Test Pit site in Illinois (93-498-5-3).

Close-up view of retrieval demonstration at Caterpillar Cold Test Pit (93-498-1-8).

CONTAMINATION CONTROL UNIT

Demonstration of this technology was completed in FY-93.

Principal Investigators

- Guy G. Loomis and 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 x 26 ft trailer. The vacuum, a nuclear grade system with a HEPA filter and a critically safe 55-gallon 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-gallon tank. The stabilizer and concentrate are stored in 5-gallon 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-gallon 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 reapplication.

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, 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 encapsulant (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 also was 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 1.5 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 environmental restoration use throughout the DOE complex.

Collaboration/Technology Transfer

Consideration is being given to remotizing this kind of technology. The remote control technology of the Remote Excavation System (RES) or digface 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.

The system is being used throughout the DOE complex. Disclosure of this research has been at the international level. The project was presented in a report entitled "Contamination Control During Transuranic

Waste Handling Operations" at the 1994 Second International Symposium and Exhibition on Environmental Contamination in Budapest, Hungary. Privatizing the technology for assistance in performing waste site remediations is being considered.

Contamination Control Unit at retrieval site.

Applying 3M foam to an incline at a retrieval site during the 1993 BWID summer demonstration (93-507-2-25).

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 chemicals but the products 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, Environmental Protection Agency, and Department of Defense sites that need some type of retrieval are all candidates for this type of dust control. Their application also might 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 digface 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 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 cents per pound or 5 cents per square yard when applied to soil surface at field effective rates. A nonpregelled product separates in the tank and tends to clog the spray nozzle.

XDCA costs about 50 cents per gallon for the concentrate or about 16 cents per square yard 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.

Collaboration/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 enhances

Applying natural polysaccharides to an
incline at a retrieval site during the
1993 BWID summer demonstration
(93-499-1-23).

viability of polysaccharide products
as well as biodegradation and short-
term low residue requirements. The
work was reported September 1993
in a Westinghouse Hanford Com-
pany report entitled "Fixation of Soil
Surface Contamination Using Natural
Polysaccharides," WHC-EP-688.

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 waste-handling operations. As the transuranic 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 transuranic waste retrieval/treatment operation.

Technology Attributes

The electrostatic curtain technology controls the spread of transuranic contamination during waste retrieval/treatment operations. This technology minimizes 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.

Collaboration/Technology Transfer

Full-scale demonstration of this technology has not been completed. Lab results were presented at the Waste Management 91 Conference in a report entitled "Electrostatic Curtain Experiments." 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 systems (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 also can 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-, 4-, 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.

Collaboration/Technology Transfer

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

Through collaboration with a private-sector partner, technology is already developed in the commercial sector. The results were presented at the Waste Management 94 Conference in a report entitled "Removal of Overburden Soils from Buried Waste Sites."

Overburden removal demonstration at
INEL Cold Test Pit during 1993 BWID
summer demonstration (93-588-1-26).

REMOTE RETRIEVAL INTEGRATION

Investigation of this technology was completed in FY-94.

Principal Investigators

- Reva A. Hyde, John L. Morrison, and John K. Rawlins, INEL

Research Objective

Investigate technology to integrate individual components used for remote remediation into an efficiently operating system. Develop a remotely operated excavator, design a human engineered control station, and develop the functional and operational requirements for a supervisory system using distributed control.

Technology Description

The buried waste program has centered investigation of the excavation of waste on three primary system components: a remotely operated excavator, an autonomous waste conveyance vehicle, and a telerobotic gantry crane. The telerobotic gantry crane is equipped with two manipulators attached to independent trolleys to deploy other technology for characterizing waste, controlling dust and contamination spread, cutting large objects, and performing archaeological excavations.

Conceptual design of a Human Engineered Control Station (HECS) was completed to provide controls and displays for the retrieval equipment. The design addressed controls, displays, workspace, work arrangement, and work environment.

The HECS includes a Supervisory Control System (SCS) to aid in collision avoidance and allow for data transfer between the systems. The SCS provides a broadband data highway with network capacity to carry all the data between the control trailer and the retrieval enclosure. The network makes data from each system available for use by other systems that require the information.

Waste Management/Remediation Need

Based on safety analyses done in the past, the retrieval of buried waste will be required to be performed remotely. DOE's desire to remotely retrieve buried waste and the Department of Defense's interest in remote retrieval of unexploded ordnance share similar technology needs. One need of both programs

is the development of a remotely operated excavator to perform the retrieval tasks. Radioactive contamination is a concern, but larger concerns identified in the safety analyses include explosion and fire potentials. The development of remotely operated equipment such as the remote excavator will allow the remediation operations to be performed in a manner that provides worker safety. Effective and efficient remote operations are dependent on the development of human-machine interfaces and proper system integration.

Technology Attributes

This technology aids in remotely operating excavation equipment. The HECS provides an integrated remote control mechanism that integrates human capabilities, limitations, and expectations into the design of the retrieval system to reduce potential for human error, provide an easy system to learn and operate, and reduce the ultimate investment in training.

Accomplishments

A Caterpillar 325L excavator was fitted with a commercially available open loop control system modification package to allow simple operations to be performed remotely. The system was tested at Jefferson Proving Grounds and operated satisfactorily. Development of remotely operated excavators with closed loop control was not needed as these became commercially available.

The conceptual design resulted in two distinct options: allocation of tasks based on equipment (option 1) and allocation of tasks based on function (option 2). Option 1 follows closely with standard operations where each piece of equipment has a dedicated operator. In this option, a controller would be developed for each piece of equipment. The equipment operator could operate the equipment from any workstation by plugging in the appropriate controller and selecting the appropriate software interface.

Option 2 redistributes the tasks based on function rather than on equipment operations. Generic

controllers would be used by an operator to remotely operate the desired piece of equipment, rather than having dedicated operators for each piece of equipment.

Functional and operational requirements for the SCS were developed. Each platform was to provide system specific data from appropriate resolvers to allow the SCS to determine platform configuration. Additionally, the SCS would have a subsystem to identify each platform's position and orientation. With each platform located and configured via the SCS, a graphical model of all the platforms and exclusion zones surrounding the platforms can be generated and maintained. This modeling information would then be used to perform collision avoidance chores.

The control system for an excavator and the system vision systems was mounted on the excavator to simplify remote operations. Additional operator aids that may simplify remote operations are being investigated.

Technology Transfer

Much of the technology development performed as part of this activity was done by industry. The Department of Defense has funded Wright Laboratories, based at Tyndall Air Force Base, to perform research and development on remote excavators. The buried waste program teamed with Wright Laboratories to leverage government funding in this development effort. Caterpillar was involved in specially fitting equipment to allow simple operations to be performed remotely. Testing was done at Jefferson Proving Grounds, a Department of Defense facility.

Conceptual drawing of a telerobotic retrieval demonstration using a 60,000-lb class, remotely operated excavator.

CRYOGENIC CUTTING SYSTEM

This technology will be demonstrated in FY-95.

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

Cryogenic cutting is an adaptation of the highly effective waterjet technique used in cutting a surface with a high pressure abrading substance. It uses high pressure liquid nitrogen and solid carbon dioxide to perform the cutting and abrading. This substitution removes the secondary waste-stream water as a cutting media, which is a highly desirable 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 through 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 shears. Plasma arc cutting adds risk to operations due to the flame inherent in the operation and the high temperatures involved. 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 reduce the size of materials and eliminate the secondary waste stream inherent in waterjet cutting. This project is still in a research phase and the cost-benefits are not quantified. Cost savings will be dependent

on the specific application. However, savings will be driven primarily by the reduction in secondary waste-stream handling and disposal costs.

Accomplishments

The existing cryogenic cutting system underwent extensive upgrades to improve cutting effectiveness, including enhancements to existing fluid systems for the delivery of liquid nitrogen to the nozzle, development of robust control of the nozzle actuation, and evaluation of cutting on select materials.

The nozzle was attached to a gantry crane to allow it to be operated in an 18 in. x 18 in. x 18 in. volume, allowing sufficient movement to establish cutting rates with various materials. A plywood box was opened in 15 minutes at a scan rate of 0.5 in./sec. A steel drum was opened by directing the jet around the periphery of the drum. For one revolution, the travel speed was 0.012 in./sec giving a 0.007 in.

depth of cut. At this rate eight passes were required to perforate the drum wall, which would take approximately seven hours.

Collaboration/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.

Demonstration of the cryogenic cutting system (94-555-1-15).

THREE-DIMENSIONAL DYNAMIC GRAPHIC SIMULATION OF RETRIEVAL OPTIONS

Work on this technology continues in FY-95.

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 buried waste systems analysis.

Technology Description

The graphical 3DDST will illustrate the buried waste 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.

The 3DDST consists of an array of computer hardware and software components that have been inte-

grated to allow development of three-dimensional graphical display presentations featuring proposed buried waste telerobotic retrieval technologies. During FY-95, the 3DDST will be further enhanced to integrate with and illustrate the FY-95 buried waste characterization/retrieval field test/ex situ treatment configuration options. Software equipment models will have the ability to display representative material (soil) removal performed by buried waste technologies staged at a representative model of the demonstration site.

A software model library also will be developed, consisting of the proposed buried waste technologies to be deployed for the FY-95 field test. The database will facilitate timely development of work site scenarios involving those technologies.

Waste Management/Remediation Need

The program supports the development and demonstration of technologies that can be integrated together with baseline technologies to form a comprehensive remediation system for Environmental

Management. It also is developed with the flexibility to allow Environmental Management to use it to carefully plan retrieval efforts in various waste scenarios.

The 3DDST will assist both of these needs. It is a graphical tool that facilitates comparison of the numerous systems that can be built with a myriad of alternative retrieval technologies. A software library of available buried waste or other proposed systems will be developed for fast generation of retrieval scenarios depicting use of these technologies prior to or after fabrication of the technology.

The system allows these technologies to be tested for various data parameters in a safe setting without extensive resource commitments.

The system also may be used as a training tool for personnel assigned to deployment activities involving these technologies. The 3DDST is useful for many aspects of the systems analysis effort because it can easily be modified to illustrate site specific retrieval needs/scenarios and technologies.

Technology Attributes

This graphical tool:

- Visually defines the relative merits of proposed technical development activities of the buried waste 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 alliance of DOE laboratories, Federal agencies, and universities.
- Forms three-dimensional images of several different configuration options at different DOE sites in various retrieval environments.

The 3DDST will allow researchers to perform simulated testing of technology designs and test scenarios for feasibility of success and inherent job safety. Such data may be used in the decisionmaking process related to technology development, retrieval feasibility studies, or personnel training.

Cost savings are difficult to quantify. If even one technology system can be eliminated from further consideration or one selected without extensive comparative demonstration, the savings are easily in the millions of dollars. This tool enhances planning for remedial design and operations, thereby increasing production efficiency.

Accomplishments

Cost-effective hardware and software packages were selected for the 3DDST following a technology survey. These were integrated to allow development of preliminary graphical display presentations. The 3DDST was modified, applied to selected configuration options, and programmed to demonstrate system capabilities for system analysis. Based on feedback, this work is augmented with the development of software equipment models and the ability to display representative material (soil) removal with the model. The capabilities of 3DDST were demonstrated in the field.

Collaboration/Technology Transfer

The product will be in the form of a software and associated hardware tools. The development of 3DDST involves the integration and modification of numerous commercial software products. Transfer of such a technology product likely would require involvement of each software contributor.

Commercial participants for software and hardware will be identified and obtained in the first phase of this effort. However, the potential exists for commercial application of the tool as a service to various industries for technology testing, training aids, etc. This may be accomplished through a Cooperative Research and Development Agreement with interested parties if the market exists.

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 Environmental Management elements at all applicable DOE sites as well as other complex hazardous waste sites.

REMOTE EXCAVATION SYSTEM

This technology will be applied to a specific waste site in FY-95.

Principal Investigators

- Brad Richardson, Stephen Killough, and David Thompson, Oak Ridge National Laboratory
- U.S. Army

Research Objective

Assemble a system to remotely excavate radioactive waste, unexploded ordnance, and other hazardous wastes. Demonstrate and evaluate the remotely operated excavation technology in the field in a specific 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 has been modified 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 has 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 visual contact with the vehicle for operation.

The RES will be used to remove the overburden and to manipulate the disposal casks so rigging can be attached. Current plans are for the majority of the casks to be transported to the Interim Waste Management Facility (IWMF) staging area where they will be placed in the standard IWMF 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, which is 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. At each of these demonstrations, the relative performance benefits of teleoperation and telerobotic excavation were evaluated and documented. The demonstrations showed that the system can be operated remotely to effectively excavate buried waste and unexploded ordnance. The advanced control technology and computer-assisted operations made excavation relatively easy for both inexperienced and experienced operators.

FY-95 testing at the ORNL Hill Cut Test Facility will compare radiation exposure risks during manual retrieval operations versus exposures using telerobotic excavation, modify the end effector with a quick disconnect mechanism, and improve operator interface and control algorithms.

Collaboration/Technology Transfer

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

Remote excavation operations at the INEL Cold Test Pit during BWID summer demonstration (93-575-1-5).

REMOTE WASTE CONVEYANCE, REMOTE OPERATED EXCAVATOR (REMEX), AND INNOVATIVE END EFFECTOR

This technology will be included in the FY-95 demonstration.

Principal Investigators

- Phillip M. Rice and Bradley M. Gardner, INEL
- RAHCO International
- SPAR Aerospace Ltd.
- RSI Research Ltd.

Research Objective

Develop equipment to perform remote retrieval of buried transuranic waste with reduced dust generation. Remote retrieval will reduce the risks to workers and the environment, and the lowered dust level will reduce the potential spread of airborne contaminants. In order to meet this objective, the purpose of this project is to develop a remotely controlled conveyance system, an innovative end effector (IEE), and a remote excavator to allow digging and transfer of retrieved waste from the digface to the processing or packaging area. The design of the three primary components of the system will be integrated to optimize the performance of all three.

Technology Description

Remote Operated Excavator

SPAR Aerospace Ltd. and RSI Research Ltd. have modified a conventional Hitachi EX200LC

excavator for remote operation. The Remote Operated Excavator (REMEX) was included in the full-scale remote retrieval demonstration in FY-94. The modifications include the use of coordinated control technology to control the remote operation of the excavator. The implementation of coordinated control technology has been supported by the University of British Columbia, which has developed this technology for use with heavy equipment operation. A four degree of freedom joystick, which is mounted on the arm of the operator's chair, controls the excavator digging functions. The conventional track control foot pedals are maintained.

With the new technology of coordinated motion control, the operator uses a single joystick to control the excavator arm. There is one-to-one correspondence and proportional speed control between the motion of the master controller and motion of the bucket. The primary mode of operation is from a remote control operating station that can be located up to 2,000 ft from the REMEX and is linked to the REMEX by a telemetry cable. All REMEX functions that could

be performed from the cab can be performed from the remote control station. The REMEX was modified to a front shovel configuration to accept the IEE and thumb for the FY-94 demonstration.

The FY-95 demonstration calls for removal of a limited portion of a buried waste pit known as a hot spot. Removal of the hot spot without disturbing the surrounding waste requires that the excavation be accomplished from an abovegrade position. This requires that the IEE design be modified from its current front shovel configuration to a backhoe configuration. This will allow the REMEX to operate from the abovegrade position and dig down into the waste while maintaining the functionality and dust-free dumping capability of the current IEE design.

The REMEX will be modified to accept the backhoe configured IEE during FY-95. Other upgrades such as a stereo vision system, ruggedized sensors, and addition of coordinated control of the thumb will be added to enhance the REMEX performance and improve the human-machine interface.

Innovative End Effector (IEE)

During FY-94, the REMEX was fitted with an IEE to reduce dust generation during digging and dumping operations. The IEE consists of three structural assemblies — a thumb, an attachable/detachable integrated transfer module (ITM), and a shovel assembly and the necessary actuating linkage and hydraulic cylinders. The thumb has proven to be extremely versatile, dexterous, and productive in handling the expected waste forms. The ITM acts as a detachable loading, handling, and conveyance bucket when digging, handling, and conveying 55-gallon drums, dirt, and small debris. The detachable ITM essentially eliminates dumping at the digface, thereby reducing dust and the potential spread of airborne contaminants.

During FY-95, the IEE will be modified from a front shovel to a backhoe configuration to facilitate digging from an abovegrade position for operations such as hot spot retrieval. Further modifications include improved sensors, streamlined teeth and overflow slot designs, and reduced flat surfaces for dust reduction.

Remote Conveyance Vehicle

The remote conveyance system was designed and provided by RAHCO International and SPAR Aerospace. The FY-94 work included design, development, and demonstration of a track-mounted telerobotic transport vehicle (TTV), remote operator control station, and waste transport container. The TTV transports the loaded/unloaded transport containers and ITMs. The TTV is fully integrated with the end effector/waste-handling system to provide a waste conveyance solution that eliminates dust generation during conveyance operations. The TTV is designed as a multiple function vehicle. First, it conveys the empty waste transport containers and ITMs from the storage area to the excavation site. Second, it serves as a transfer station at the excavation site by (a) supporting the transport container, (b) opening, closing, and locking the container lid, and (c) providing a staging platform for the empty ITM. Third, it conveys full containers and ITMs from the excavation location to the dumping/unloading location.

The conveyance vehicle is propelled by a set of hydraulic motor-powered crawler tracks that provide stability on slopes and excellent maneuverability. One track is mounted rigidly to the frame while the second track is connected by horizontal pivot pin. This minimizes racking of the frame as the conveyance vehicle travels over irregular terrain. Employing skid steering, the conveyance vehicle can turn 360 degrees on its own center on a 4.5-meter-wide path.

The 4,100-kilogram capacity waste transport container receives retrieved waste in the form of filled ITMs, 1.25 x 1.25 x 2.4-meter boxes, and many other expected, irregularly shaped, large waste items. After receiving the waste items directly or in an ITM, the container is closed and automatically sealed and locked to contain any dust generated during conveyance. The container is a steel structure approximately 1.5 meters wide, 1.5 meters high, and 2.8 meters long, weighing approximately 1,270 kilograms empty. A pocket located in the bottom of the container is tapered to self-align the ITM during loading.

In operation, the IEE selectively retrieves the expected waste forms and places the collected waste in the waste transport container. For large waste items, the IEE places the item directly onto the container floor. For dirt, debris, and 55-gallon drums, the excavator scoops the materials into the ITM, swings the filled ITM over the transport container, and lowers the ITM into the container pocket where it is detached. An empty ITM, staged on the conveyance vehicle, is then attached to the IEE and swung back to the digface. Simultaneously, the container lid is closed and the filled ITM secured in the container. The ITM is then carried by the conveyance vehicle to a storage area receiving station where the filled container and enclosed ITM are off loaded. An empty ITM and an empty container are loaded onto the conveyance vehicle. The vehicle then travels back to the digface.

From its inception, the conveyance vehicle was intended to be capable of semi-autonomous operations. The TTV developed in FY-94 was the first step toward this capability. It was designed to prove the hardware and operational concepts for buried

waste conveyance and to demonstrate integration with the IEE and REMEX. The second step, to be taken in FY-95, is to upgrade the control system to provide this capability. The TTV control system will be upgraded to a self-guided transport vehicle (SGTV). The SGTV will use a state-of-the-art video tracking system along with mission planning software to preplan and then semi-autonomously perform the conveyance operations. This will greatly enhance the operational flexibility of the system and relieve the operator of the highly demanding task of piloting the vehicle in a teleoperated mode. Other system upgrades such as an improved engine, hydraulic system, and collision avoidance detection will be deployed on the SGTV.

Waste Management/ Remediation Need

The IEE and SGTV are designed to reduce contamination spread during waste remediation, primarily during dumping and conveyance. Digging and dumping have been shown to be the primary functions that contribute to contamination spread. The IEE and SGTV eliminate dumping at the digface and, along with

contamination control during retrieval, will greatly reduce potential contamination spread during retrieval operations. The SGTV addresses the need for a vehicle that can operate remotely on the variable terrain in an unstructured environment expected in retrieval areas.

Technology Attributes

Advanced conveyance systems testing will:

- Minimize contamination spread during waste remediation
- Minimize personnel exposure and health risks
- Meet waste retrieval and transfer rate goals
- Assist Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) retrieval option assessment
- Assess an integrated system for complete retrieval of buried waste.

Accomplishments

A full-scale demonstration of the integrated system was completed in FY-94. The first phase consisted of a retrieval demonstration using the REMEX and IEE in a controlled environment to facilitate dust and

rare earth tracer measurements. The second phase consisted of an outdoor demonstration including all of the components of the integrated system— the REMEX, IEE, and TTV.

Results from the Phase 1 tests show the IEE to be a very effective and reliable system for retrieving and transporting buried waste through the excavating process. The process of using the IEE resulted in dust spread that was two orders of magnitude below the test goal. The transfer of the ITM from the excavator to the transfer point was accomplished with virtually no visible dust or tracer spread as expected. The Phase 1 demonstration successfully proved that the concept of eliminating the dumping at the digface is a viable, immensely practical approach to limiting potential contamination spread during buried waste retrieval. Controlling the dust generation at the source of digging combined with the IEE's inherently dust-free dumping operation should result in greater than 98% reduction in dust spread over cases without regard to contamination control.

The Phase 2 test combined the REMEX, TTV, and ITM system to demonstrate the integrated systems approach of the design in a full-scale retrieval. The TTV and IEE were designed as a system for enhanced performance. The spring bed on the TTV assisted with easy alignment and transfer of empty ITMs from the TTV to the REMEX, while the tapered recess in the Waste Transport Container assisted with alignment during depositing full ITMs. The systems approach provided for smooth and easy integration between the TTV, IEE, and REMEX.

During the FY-94 demonstration, the IEE proved that dust-free dumping is an efficient, effective means for reducing contamination spread during retrieval operations. The IEE design can provide the same capability as standard end effectors for retrieval operations without the inherent problem of contamination caused by a dusty dumping process. The integrated systems design approach for the development of the REMEX, IEE, and TTV provides an effective solution for remote retrieval and conveyance of buried waste. This demonstration successfully showed that buried waste retrieval

can be performed remotely at low cost, at reasonable throughput rates, and with greatly improved safety for the worker and environment.

During FY-95, the TTV is being upgraded to an SGTV. The REMEX will be modified to a backhoe configuration, and the IEE will be modified to attach to the REMEX in this configuration.

Collaboration/Technology Transfer

The concept and design of the system was developed by RAHCO International in conjunction with SPAR Aerospace and RSI Research. Patents are being pursued for various designs by these companies. Disclosure of this research through professional journals and presentations at technical conferences will enhance opportunities for this type of technology to be further developed by private industries.

A filled integrated transfer module (ITM) is placed inside the waste transport container on the telerobotic transport vehicle (TTV) (94-1187-2-11).

The TTV developed in FY-94 will be modified to incorporate the self-guidance control system and numerous mechanical system upgrades.

COOPERATIVE TELEROBOTIC RETRIEVAL

This technology will be included in the FY-95 demonstration.

Principal Investigators

- Kevin M. Croft and Scott M. Allen, INEL

Research Objective

Develop the capability to perform selective, or surgical, retrieval at a buried waste site. Two robotic manipulators will be installed on a gantry crane 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. Operations will be facilitated by deployment of an array of ancillary tools.

Technology Description

A field test will evaluate the ability of the gantry crane to transport dual manipulation capability to the digface. The delivery system will be used not only to transport the manipulators, but also to deploy digface characterization equipment and other equipment required at the digface.

The 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 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.

Various buried waste support technologies will be integrated for deployment during the FY-95 field test to provide a common platform, the gantry crane. The gantry crane will be equipped with two cooperative telerobotic manipulators [multi-manipulator capability (MMC)], a telescoping mast, and a hoist from which the ancillary tools will be deployed.

The crane system will be used to support archaeological excavations (soil vacuum and sundering equipment), digface characterization [INEL radiation, magnetism, and volatile

organic compound (VOC) sensors, and Pacific Northwest Laboratory radar], waste retrieval from the excavation (slings and/or grapple), and delivery of waste to the proposed transport system (hydraulic grapple to interface with excavator ITM).

Accomplishments

Prior year progress has included the purchase of the gantry crane and the associated deployment mechanisms, the MMC and hydraulic drive unit, and components of the systems control unit. The requirements for a delivery system that could be deployed at a buried waste pit digface and the capabilities of currently available delivery systems have been determined. A vacuum system and related end effectors to remove soil and debris from around a buried object were selected. The control of dual, cooperative, manipulation activities and the technologies developed under separate previous year's research efforts (soil vacuum/sundering tool) will be integrated for use in FY-95 field test.

Waste Management/ Remediation Need

Current buried waste retrieval scenarios indicate that it may be desirable to selectively retrieve some objects uncovered at the digface. Intact drums, machining tools, potentially explosive objects, and other hazardous articles could be carefully removed from the site with this technology and processed separately from the balance of materials.

Technology Attributes

The system has been developed to demonstrate that available technology can be deployed in a realistic waste remediation scenario by a cooperative telerobotic platform. The system has been developed with versatility to allow Environmental Management to challenge its capabilities for data to support the claims that such activities can be performed remotely to minimize worker exposure.

The research:

- Evaluated the delivering system's ability to transport equipment, such as robotic manipulators, to the buried waste pit site.

Gantry crane system used for testing at the INEL (95-47-1-5).

- Designed and fabricated a remotely operated vacuum system to remove soil and debris from around objects to be surgically removed.
- Developed and evaluated a control system capable of controlling the required axes of motion.
- Developed and evaluated the capability to control two robotic manipulators used in cooperative activities.

Collaboration/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.

Two robotic manipulators on the INEL gantry crane system.

MACHINE HEALTH MONITORING

Lab-scale testing of hydraulic systems will continue in FY-95.

Principal Investigators

- Robert S. Schley, INEL
- John Steel, 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 must be more than informational, but use data to limit 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 sensor capability demonstrated in the remote area vehicle and excava-

tor 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 also may have to be developed. The algorithms will analyze trend data in real time to determine failure prediction data on specified buried waste equipment.

Waste Management/ Remediation Need

Monitoring the status of retrieval equipment 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 down time 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 onsite "feel" of the equipment and potential failure is not possible.

The machine health monitoring system is intended to monitor remotely operated equipment in real time and to provide diagnostic information about that equipment in the same way stationary plant equipment has been monitored. This technology can be used on any equipment but the greatest benefit is believed to be on equipment used for hazardous waste retrieval and cleanup.

This technology is still in a research phase and, therefore, the cost-benefits cannot be determined yet. However, this technology will reduce unscheduled down time, which will reduce worker exposure to hazardous environments by eliminating the requirement for maintenance personnel to enter hazardous environments to repair or remove

broken equipment. Case studies indicate that predictive monitoring programs can achieve cost savings from 35% to 80% over preventive-type maintenance programs.

Accomplishments

Two test benches were fabricated to monitor real-time operating parameters of hydraulic components including flow rates, inlet and outlet pressures and temperatures, and vibrations. Operational and failure data were collected for four different failure modes on a fixed displacement gear pump. Based on the collected data, a failure algorithm development was initiated.

Collaboration/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,

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

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.

System health monitoring low-volume test bench and data acquisition equipment (94-571-2-11).

System health monitoring high-volume test bench (94-571-1-6).

TREATMENT

Point of Contact

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VITRIFICATION OF LOW-LEVEL RADIOACTIVE NITRATE SALTS AND SOILS

Demonstration of this technology was completed in FY-93.

Principal Investigators

- Peter Shaw, INEL
- 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 (15–50 wt%) and Acid Pit soils (40–80 wt%) mixed. Glass oxidation-reduction and handling properties are controlled by using additives such as boric acid and carbon (0–10%). 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:

- Produces a durable waste-form glass that passes the toxicity characterization leaching procedure and shows no nuclide

(uranium transuranic, cesium) leaching

- 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.

Accomplishments

The lab-scale vitrification:

- Tested spiked salt soil mixtures with additional hazardous (0.7% lead) and radioactive (50 pCi/g of 234-U, 100 pCi/g of 242-Pu, 100 pCi/g of 241-Am) metals
- Produced high sodium and borosilicate glass samples for future leach tests
- Melted a variety of salt/soil/additive ratios of actual Pad A salts (15–50 wt%) and Acid Pit soils (40–80 wt%) with a recommended salt-to-soil ratio of 0.43
- Controlled glass oxidation-reduction and handling properties by using additives such as boric acid and carbon (0–10%) with a maximum alkali content of 25%.

Collaboration/Technology Transfer

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.

The collaboration between DOE/INEL Environmental Management 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 makes 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.

PLASMA CENTRIFUGAL FURNACE

Demonstration of this technology was completed in FY-93.

Principal Investigator

- Dan Battleson, Mountain States Energy, Inc.

Research Objective

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

Technology Description

The plasma centrifugal furnace 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 furnace, 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 furnace, 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 transuranic), 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 plasma centrifugal furnace technology renders 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 furnace 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 furnace has been established for feeds processed to date (mainly INEL soil). A continuous emissions monitoring system and total hydrocarbon monitoring system meeting the latest Environmental Protection Agency standards have been installed at the furnace testing facility in Butte, Montana. A Superfund Innovative Technology Evaluation test program has been initiated. Three of the planned 16 runs of the test program are completed. The results indicate that the slag produced in these tests also passed toxicity characterization leaching procedure (TCLP) standards and greater than 99.999% of organic material was destroyed.

Since July 1992, four tests have been completed. The first test provided a shakedown of the furnace 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.

Collaboration/Technology Transfer

This technology is an integral component of a commercial remediation process that is proposed and being evaluated by the INEL Environmental Restoration Program. This research was published in July 1994 by Mountain States Energy in a two-volume technical report entitled "Test Results from Plasma Centrifugal Furnace Demonstration under the Buried Waste Integration Demonstration." Other private-sector contractors that may be constructing waste-processing facilities have access to this information and will hear about this and other thermal treatment work through marketing efforts.

Plasma centrifugal furnace at the
Mountain States Energy test facility,
Butte, Montana.

PLASMA FIXED HEARTH PROCESS

Demonstration of this technology was completed in FY-93.

Principal Investigators

- Ray Geimer, Science Applications International Corporation
- Dan Battleson, Mountain States Energy, Inc.

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 transuranic 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 transuranic), mixed wastes, and contaminated soils. These types of wastes are buried or stored at DOE sites 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 transuranic 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.

Accomplishments

A new generation PHP was constructed by the DOE Office of Technology Development's Mixed Waste Integrated Program for further testing. Six performance tests were conducted in this pilot-scale PHP facility. Three to four barrels of simulated waste materials per hour were processed. The waste consisted 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-gallon 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 550lb/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.

Collaboration/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.

Fixed hearth and plasma torch at the
Retech test facility in Ukiah, California.

Artist rendition of plasma hearth
process pilot-scale melter.

MODELING OF THERMAL PLASMA ARC TECHNOLOGY

This technology was developed in FY-94.

Principal Investigator

- Michael G. McKellar, INEL

Research 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 simulates a variety of plasma arc waste treatment facilities. It determines 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 have been 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 offgasing. 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.

Accomplishments

The FIDAP code (a commercial code) to calculate heat transfer has been modified and two-dimensional axisymmetric transferred dc arc model validated. The effects of a molten metal pool on electric field and heat transfer via FIDAP and performed chemistry code simulation have been calculated.

Collaboration/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 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.

Results from a simulation of U.S.
Bureau of Mines plasma arc melter.
The effects of a molten metal pool on
the velocity field (top) and the
streamlines (bottom) of the slag are
shown.

STRATEX

This technology was developed in FY-94.

Principal Investigators

- Robert Peters, Argonne National Laboratory
- Leo V. Weitzman, LVW Associates

Research Objective

Develop and evaluate STRATEX, an integrated system of several technologies for processing 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 for 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 do not take advantage of synergistic effects and thus are costly, complicated, and good only for small-volume, specialized operations. Remediation goals require both destruction of organics and stabilization of remaining hazardous metals including radionuclides.

Technology Attributes

Instead of sequential treatment of thermally desorbing soil and solidification, STRATEX combines both steps into 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.

Accomplishments

A laboratory feasibility study of STRATEX evaluated and optimized 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 were determined. STRATEX has been evaluated for specific DOE site soils and contaminants. Performance and cost have been estimated and compared with existing technologies.

Collaboration/Technology Transfer

A private independent consultant is involved as a joint participant to assist in timely technology transfer. A private environmental restoration and waste management 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.

SECONDARY TREATMENT OF OFFGAS USING NONTHERMAL PLASMA

This technology was lab tested in FY-94 and will be demonstrated in FY-95.

Principal Investigators

- Louis Rosocha, Los Alamos National Laboratory
- 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 (HVPs) in melter offgases.

Technology Description

Nonthermal electrical discharge plasmas can promote favorable chemistry for the destruction of hazardous chemicals. Electrical energy directed into the process chemistry creates highly reactive free radicals that oxidize or reduce pollutants, fragment pollutants directly, or promote excited-state chemistry.

Silent discharge plasmas consist of two parallel metal electrodes with a dielectric barrier covering one or both electrodes. A high voltage is applied between the electrodes, creating microdischarges in gases

flowing between them. The electrical energy is channeled into free radical production. This 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.

Competing technologies for VOC treatment include thermal catalytic incineration and activated carbon treatments. Selective catalytic reduction (SCR) techniques compete in the treatment of sulfur and nitrogen oxides. The NTPs have the advantage of potentially being able to treat each of these waste gases as well as HVPs simultaneously. This technology may not compete well on operating cost because electrical processes are generally more expensive than thermal processes. Nonetheless, it may compete well on a more global scale because of the ability to treat several waste gases simultaneously and because the process produces less greenhouse gas than thermal treatments.

This is an emerging technology, so little cost data are available. One baseline comparison is for VOC abatement where it is projected that NTP is two to four times cheaper per kilogram of VOC than activated carbon.

Accomplishments

During FY-94, considerable effort was expended in defining a surrogate offgas mixture to represent

generally expected arc melter outputs. This work involved the examination of large data sets from arc melter tests and offgas simulation calculations, interfaces with DOE and U.S. Bureau of Mines personnel, and projections of offgas outputs based on a variety of expected feed material.

A surrogate mixture composed of SO₂, NO, a chlorocarbon, and a chloro-fluorocarbon was specified and 10 bottles of gas were ordered from a specialty vendor. Conceptual designs were formulated for lab-scale evaluation tests at Los Alamos National Laboratory and demonstration testing on a bench-scale arc melter. Lab-scale apparatus for low temperature (<300°C) testing was designed and assembled and testing on the surrogate mixture started. Additionally, several buried waste program tasks were completed.

A laboratory-scale NTP system was demonstrated for the removal of various organics and HVPs that are characteristic of a high temperature (>500°C) arc melter operated in a reducing mode. Oxidation of HVPs and destruction of organics were

assessed in various atmospheres, including those with high particulate loadings and at various flow rates and surge conditions.

Destruction of organics did occur. Feasibility tests for HVPM vapors are progressing. The design-determination/scaling tests are almost complete and a prototype system has been selected. The demonstration equipment is being designed and constructed.

Collaboration/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 industries 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. Research was presented at the First International Conference on Advanced Oxidation Technologies for Water and Air Remediation in June 1994 in London, Ontario.

Secondary treatment of offgas using nonthermal plasma.

GRAPHITE DC ARC FURNACE

Work on this technology continues through FY-95.

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.

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).

Waste Management/ Remediation Need

The plasma arc technology can treat any type of buried waste (hazardous, low level, and transuranic), 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.

Technology Attributes

The Mark II has several advantages:

- It can handle objects as large as a 35-gallon 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 transuranic) 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 offgasing, thereby reducing secondary waste.

Competing technologies include other arc-melter designs and joule-heated melters. Other arc melters, or plasma furnaces, include designs using single metal electrodes and the arc melter at the U.S. Bureau of Mines that uses three graphite electrodes. The single, graphite electrode design has the advantage of potentially requiring less maintenance than multiple electrode designs, while the use of graphite increases electrode lifetime with respect to metal electrodes.

In general, arc melters have higher throughput capabilities than joule-heated melters. Arc melters are well suited for contaminated soils and containers because of the high melting points required. Although data are available indicating a cost savings, it is not sufficient to quantitatively state the difference at this point.

Accomplishments

An engineering-scale furnace, the Mark I, has been built and demon-

strated 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.

The Mark II furnace was tested at higher throughputs than the Mark I using a continuous processing mode. The operation of the furnace is being evaluated from the standpoint of materials feeding, glass and metals pouring, electrode design, stability, and overall operability including offgas. A material balance has been established. Submerged and unsubmerged arc operations will be compared. In the submerged arc operating regime the Mark I is very efficient at transferring energy into the melt and not the furnace plenum. Testing arc regimes on the Mark II will be complete in FY-95.

The difference between dc arc and joule-heated melters or in situ vitrification is the relative rates at which material is processed. The dc arc is capable of processing material

at a much faster rate due to the high temperature arc zone. The dc arc technology has been demonstrated to process solid waste at 1 kilowatt hour per pound of material processed. This value is better than any reported value for the plasma torch systems and is equal to that for joule-heated melters and the in situ vitrification process.

Collaboration/Technology Transfer

Other commercial entities have expressed interest in the melter technology. Technology transfer is occurring with university (Massachusetts Institute of Technology) and industry (Electro-Pyrolysis) partners on the project. Technical progress reports and design data will be transferred to other projects, especially similar vitrification efforts.

Schematic drawing of the Mark II furnace.

Mark II furnace at MIT.

VITRIFICATION FURNACE IN SITU REAL-TIME MEASUREMENTS

This technology was initiated in FY-93 and continues through FY-95.

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 innovative diagnostic tools for monitoring arc furnace treatment processes in situ in real time.

Technology Description

High temperature 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.

In situ gaseous and particulate emission measurement and analysis in real time are tested on specially deconfigured plasma sources. Molecular emission analysis and particle size and velocity determina-

tion are used to monitor composition of solid material at various stages of processing.

Waste Management/ Remediation Need

High temperature real-time measurement systems monitor arc technologies used to treat any type of buried waste (hazardous, low level, and transuranic), along with any contaminated soils and containers. Measuring the destruction efficiency of organics, volatilization, and incorporation of metals (both radioactive and hazardous) are essential for successful stabilization and a suitable final waste form. Measuring and adjusting parameters also can minimize ash and secondary waste.

Technology Attributes

The in situ high temperature monitoring and measurement system should:

- Monitor the destruction of hazardous materials
- Be durable and able to monitor the offgas system from a full-scale production furnace
- Work on a variety of arc furnaces used to treat any type of buried

waste (hazardous, low level, and transuranic) along with any contaminated soils and containers

- Assist in determining if the final waste form (slag, solidified residue) is durable and meets specifications
- Reduce secondary waste by an improved waste form, increased processing efficiency, and decreased offgasing.

Accomplishments

An engineering-scale furnace has been built and developed with improved diagnostics. Surrogate waste has been treated with temperature and composition monitors used. 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.

Molecular emission analysis, particle size and velocity determination, and

composition of solid material at various stages of processing were measured. The continuous online offgas system was used to assist in the material balance and provide input, along with the temperature sensors to optimize the furnace design. Further development of the process diagnostics continues in FY-95.

Collaboration/Technology Transfer

Other commercial entities have expressed interest in the melter diagnostic technology. Technology transfer is occurring with university (Massachusetts Institute of Technology) and industry (Electro-Pyrolysis) partners on the project. Technical progress reports and design data will be transferred to other projects, especially similar vitrification efforts.

Millimeter-wave radiometer temperature measurement setup in the Mark II furnace.

In situ microwave plasma element sensor.

ARC MELTER VITRIFICATION

This technology was initiated in FY-92 and is continuing through FY-95.

Principal Investigators

- Gary L. Anderson and 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 and mixed hazardous wastes and buried or stored soils.

Technology Description

A plasma arc furnace pyrolyzes and combusts organic materials and melts residual inorganic materials with an electric arc. The American Society of Mechanical Engineers (ASME)/U.S. Bureau of Mines plasma furnace — a 1.5-MVA, 1.5-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. Upon cooling, the resulting molten slag 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
- Extent of immobilization of radioactive and hazardous waste
- Recovery of valuable metals.

Costs savings have not been quantified. The key advantage of arc melter technologies is the ability to process a wide variety of heterogeneous waste into a durable glass ceramic waste form that is more leach resistant at less volume than other waste forms, such as compacted or cemented incinerator ash. Savings are realized when the ultimate disposition of the waste form is determined through less volume and less stringent requirements.

Accomplishments

The existing offgas system components can be modified for transuranic surrogates and heavy metals containment. Approximately 20–30 metric tons of simulated waste could be processed in each melt campaign, or about 4–6 metric tons per day. Surrogate wastes, including soils, metals combustibles, and sludges, were prepared and incinerated. Surrogates would also be used

as appropriate in preparation for actual TRU processing.

Research on equipment for gas handling, cleanup of secondary waste, and reducing plasma energy requirements further should reduce downstream costs. Experiments included analysis of slag and metal phases, offgas, and offgas system residues. The melt campaign is complete. Cooperative Research and Development Agreements are being finalized and a complete interim technology evaluation report is being written.

Collaboration/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 with industrial partners are being sought to speed completion of the demonstration project and accelerate technology transfer to the private sector.

Continuous tapping of slag to the slag mold.

N93 0031

U.S. Bureau of Mines three-phase arc melter furnace at the Albany Research Center, Oregon.

PROMPT GAMMA NEUTRON ACTIVATION ANALYSIS

This technology will be demonstrated in FY-95.

Principal Investigator

- Robert Gehrke, INEL

Research Objective

Develop and performance test Prompt Gamma Neutron Activation Analysis (PGNAA) as an online, nonintrusive method for the assay of waste material prior to, during, and following vitrification.

Technology Description

This proposal targets the need for on-stream, nonintrusive elemental assay of the key elements associated with waste material prior to, during, and following the vitrification process by the identification and measurement of relative concentrations. Beyond the regulatory requirements, there are technical needs associated with the characterization of waste selected as feed stock for vitrification and during the certification process itself. Knowing the constituents in the waste facilitates selection of proper additives to be introduced during vitrification.

A target waste glass formulation is sought that has the appropriate processing properties and adequate structural integrity leach resistance

and other attributes. It is also useful to identify constituents that are not incorporated into glass such as volatile metals, chlorides, sulfate, and combustible materials. PGNAA provides a method for the assay of waste material prior to, during, and following vitrification. Activation of hazardous metals enables detection and quantification. The detector for these activated metals is the gamma spectrometer.

Waste Management/ Remediation Need

High temperature processing of mixed waste must generate minimal secondary waste, produce a certified stable final product, and require minimal nonwaste ingredients. Retrieved or packaged waste contains a variety of compounds that can affect final waste form, generate secondary streams, and cause problems processing at high temperatures. During treatment chlorides, sulfates, and volatile metals might escape if in high concentrations. Base ingredients such as silica, alumina, and calcium affect the melt temperatures and waste form durability. Additional additives might not be needed for processing if

certain waste types are combined. Noninvasive assay during the thermal treatment process permits adjustment of these key elements through addition of appropriate chemicals or materials so that the final vitrified product meets final waste form acceptance criteria and waste loadings are maximized.

Technology Attributes

PGNAA assists in producing a final waste form that meets specifications such as final water solubility, compression strength, and leachability. This technology enables evaluation of waste as it is loaded into the melter and while melting occurs. The principal attributes offered by this technology are improved accuracy, confidence in estimates, and assay of waste during processing. The technology should decrease the secondary waste and help in production of a higher quality final waste form. Waste can be treated appropriately minimizing additives, melter damage, and treatment and handling.

If this assay is not performed, waste might have to be retreated and optimizing treatment as waste stream

varies is much more difficult. Cost savings of 400% are estimated based on decrease in waste volume needing treatment, decreased volume of secondary wastes, and elimination of most rework. Further savings will be realized with reduced waste handling and reduced disposal costs.

Planned Research

The PGNAA will be tested on surrogate material and calibrated for use in assay prior to and during the vitrification process. The technology is to be then demonstrated at the dc arc melter furnace at the Massachusetts Institute of Technology.

Collaboration/Technology Transfer

This technology is planned for implementation by the INEL Environmental Restoration Program if vitrification is used in Pit 9 or the Waste Experimental Reduction Facility. Opportunities exist for private-sector involvement in both development and commercialization of this technology in other areas where on-line analysis of high temperature products is needed. Applications include Superfund site

and mining waste processing, and waste solidification systems. Other nuclear institutions may aid in further research or be interested in testing systems particularly for spent fuel monitoring and waste characterization. Disclosure of this research through professional journals and presentations at technical conferences will enhance opportunities for transfer of this technology to private-sector industries.

Prompt gamma neutron activation of vitrified material. Californium-2562 source is in polyethylene block (right) (94-1024-2-2).

CONTAINMENT

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INNOVATIVE GROUTING AND RETRIEVAL

This technology was demonstrated in FY-94.

Principal Investigator

- Guy G. Loomis, INEL

Research Objective

Demonstrate an innovative grouting/retrieval concept for application in buried transuranic waste sites. This concept provides both containment and retrieval contamination control by reducing subsidence and water intrusion in the grouted waste as containment and reducing the spread of dust (and thus contamination spread) during retrieval if this option is chosen.

Technology Description

The innovative grouting/retrieval technology involves three operations: grouting, fracturing, and retrieval. The first step is to grout the waste and surrounding soil, causing an agglomeration of fine soil particles that may have become contaminated and waste itself. Buried waste is jet grouted at high pressure (6000 psi). A Casa Grande drill with a high pressure, high volume pump was used in this demonstration. The machine drills down through overburden and soil/waste.

Grout is injected into the waste through a hole immediately above the drill bit. Mixing occurs as the shaft revolves while the entire drill assembly is withdrawn. A shroud and HEPA system help contain any contamination by removing dust and retaining waste that escapes agglomeration from the injected grout and drilling liquids. The fine silty clay interstitial soils and waste become intimately mixed with the grout filling 60–90% of the voids in the waste matrix and 40–60% of those in the soil.

After curing the monolithic grouted block can be left in place as an interim improved storage mode for up to 20 years. At any time the block can be fractured for subsequent removal. Fracturing can be done with explosives, mechanically, or by demolition grouts.

Once the fracturing has occurred, any number of tools can be used for excavation such as a bridge crane apparatus placed over the pit. A backhoe was used in this demonstration. Regardless of excavation tool, fractured chunks are excavated releasing less dust than ungrouted

waste due to the agglomeration of fine soil particles and waste contaminants.

Waste Management/ Remediation Need

There are 2 million cubic feet of transuranic waste commingled with up to 6 million cubic feet of soil in shallow land burial at the INEL. Other DOE sites such as Hanford also have buried waste. Environmental Management has expressed interest in examining technologies required for the safe removal of contamination point sources or hot spots from within these waste storage sites.

Retrieval of this waste for treatment or removal is one of the waste management 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 helps to promote a successful operation. Plutonium uptake limits are extremely restrictive; therefore, there are no alternatives to strong contamination control strategies.

Technology Attributes

The innovative technology accomplishes buried transuranic waste retrieval with no contamination spread. The innovative technology of jet grouting buried waste:

- 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
- Decreases the need for elaborate contamination control strategies during retrieval and handling
- Supports hot spot retrieval by providing an effective inexpensive means of placing shoring material around the hot spot
- Supports other retrieval and containment technologies by forming a rigid digface of the grouted monolith, the ability of the grouted pit to support heavy equipment, and the compatibility of grouts with in situ vitrification.

Successful development of this system would enable remediation site contractors to reduce contamination control costs without jeopardizing worker safety. The cost estimate

of applying this technology for the retrieval of an 1-acre pit is \$15 million for retrieval and another \$15 million for repackaging and assay. This compares to the estimated cost of over \$200 million for conventional retrieval (INEL Pit 9 estimate).

Accomplishments

Bench-scale experiments determined that Type I Portland cement grout was injectable and when mixed with up to 67 wt% soil would form a concrete suitable for subsequent fracture.

During FY-94 the jet grouting retrieval technique was demonstrated in a cold simulated test pit with a positive proof of principle. A solid monolithic block was created by the jet grouting and a standard backhoe could remove chunks after fracturing.

The jet grouting and fracturing was accomplished with no airborne tracer releases above background. Each drum in the pit had been filled with 200 grams of powdered Pr as a contaminant tracer. This weight is identical to the maximum weight of lead that is allowed in each drum

based on Waste Acceptance Criteria at the time of disposal. During the retrieval, a 90% reduction of dust was observed over a baseline digging and dumping scenario in soil. Limiting dust upon retrieval limits cross contamination of equipment and surface soils. Jet grouting fully encapsulates buried waste and diminishes contamination spread upon excavation.

Collaboration/Technology Transfer

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

Casa Grande apparatus about to drill through buried waste (94-716-2-1).

Exposed monolith from innovative grouting demonstration at the INEL (94-1180-1-4).

IN SITU ENCAPSULATION OF BURIED WASTE

Lab-scale testing of these agents was initiated in FY-94.

Principal Investigators

- Jerry R. Weidner and Guy G. Loomis, INEL

Research Objective

Demonstrate an encapsulation technique using natural analogue substance such as iron and calcium precipitating solutions. These are injected into buried waste and result in a natural analogue cement that crystallizes and becomes more impervious to water migration as it ages.

Technology Description

In situ grouting involves the injection of some hardening substance into buried waste, encapsulating it in a cemented block that is impervious to water migration. The technique also can be used as an intermediate stage to solidify waste to prevent future aerosolization of contaminants should retrieval be necessary.

The hardening substance can be an analogue of a natural substance found among the waste. The hardening process might be through precipitation mimicking the 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 (CaCO_3), hematite (Fe_2O_3), and various forms of quartz (SiO_2). 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 cubic feet of buried transuranic waste mixed with up to 6 million cubic feet of soil at the INEL and similar or greater quantities of low-level, transuranic, and mixed waste buried at other DOE sites might be necessary to prevent potential health and environmental hazards.

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 transuranic 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.

In situ remediation or stabilization technologies have an advantage over traditional excavation and treatment systems in that the potential for worker exposure is significantly reduced. In situ grout technology that is capable of isolating waste material from the natural environment has several unique features.

The cost of retrieval/treatment/disposal for the INEL Subsurface Disposal Facility has been estimated between \$2 billion and \$10 billion. The cost of applying in situ encapsulation at the Subsurface Disposal Area is in the \$500-million range.

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. Microfine cements have been successfully used at Hanford in a rocky/sandy soil.

The suitability of hematite precipitating solutions was examined in laboratory-scale tests at the INEL using synthetic analogues of natural cementing agents. These iron oxide materials (hematite) are suitable for a waste encapsulation material application at the INEL Subsurface Disposal Area. The data indicate that the iron oxide waste encapsulation

materials tested should mix with INEL soil to encapsulate waste. Field tests and monitoring over an extended period of time are needed to determine the performance of the material under field conditions after pumped grouting. The waste form appears to be compatible with INEL soil and typical waste types such as found at the Radioactive Waste Management Complex. A white paper was written on organic polymer cement. Field testing awaits further funding in FY-96.

Collaboration/Technology Transfer

The technology participants from the INEL and private vendors 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 Environmental Management concerns.

Soil encapsulation media cylinders on hydraulic conductivity testing apparatus (94-1074-1-6).

Preparation of in situ encapsulation media for hydraulic conductivity testing (94-913-1-15).

MONOLITHIC CONFINEMENT

This technology was 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 by in situ grouting. Verify successful isolation by examining the inner granular regions for penetration of grout by borehole drilling. Compare the pre- and post-grout hydraulic conductivity of the matrix.

Technology Description

Monolithic confinement is a method to create a barrier to water movement in fractured rock underlying buried waste by cementing the cracks of the rock under ground. The process also immobilizes contaminants in the waste or underlying rock.

A special purpose oil field/mineral type drill (Case Grande drill apparatus in this case) drills into basaltic formations such as the basalt at the INEL. Grout (such as Portland cement) is pumped under 6,000 psi

pressure through a rotating orifice as the drill is retracted. The grout fills the inner granular cracks in the basalt while simultaneously locking contaminants that may have spread to regions below buried waste.

Waste Management/ Remediation Need

Two million cubic feet of transuranic waste is commingled with up to 8 million cubic feet of soil in shallow land burial at the INEL. Underlying this buried waste are 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 particularly to underlying aquifers without digging up the waste or disturbing the site. It complements an overall strategy of total confinement by eliminating water flow and further migration of contaminants actually in the basalt.

The in situ process is a low impact strategy for buried waste confine-

ment compared to more intrusive remediation techniques. The waste is minimally disturbed and the risk of surface contamination release is reduced. The grout also can be injected in the waste as the drill bit is retracted, further reducing waste permeability to water and subsidence.

Technology Accomplishments

Monolithic confinement was successfully tested by the INEL and Westinghouse Hanford Company at a test area near the INEL.

Reduction of hydraulic conductivity of one to two orders of magnitude was demonstrated in the fractured basaltic matrix. Grout penetrated up to 4 meters from the drill/application hole. A tracer sensitive to ultraviolet light was used to provide positive identification of grout penetration.

Forming a subsurface barrier in this manner is also a cost-effective way to eliminate the further migration of contaminants that might be present within the underlying basalt. The technique is useful on any buried waste site where contaminant spread is a problem and water

penetration through the waste needs to be reduced.

Collaboration/Technology Transfer

Personnel from Westinghouse Hanford Company are in the process of privatizing the process with a company called Applied Geotechnical Engineering and Construction, Inc. The business plan is currently being reviewed. Considerable cost savings have been demonstrated while operating for Westinghouse. The company already has its services requested with companies involved in the entire nuclear fuel cycle-public and private, state and federal, waste operations and waste remediation. The drill rig will be provided at no cost to DOE environmental restoration programs for remediation of pits and trenches.

In situ grouting rig above basaltic field
environment at Box Canyon site near
the INEL.

COLD TEST PIT

APPENDIX A

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COLD TEST PIT

An area 40 ft wide, 228 ft long, and about 10 ft deep was excavated in 1988 about 600 ft south of the Subsurface Disposal Area (SDA) in the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory. 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 also was 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 characterization and retrieval demonstrations. The total size of the cells is 40 ft wide, 43 ft long, and 12 ft 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 Digface Demonstration and will be used as a calibrated test cell for future demonstrations. The dimensions of this cell are 32 ft wide and 8 ft 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.

Graphic layout of the INEL Radioactive Waste Management Complex and the Cold Test Pit.

Layout of the INEL Cold Test Pit.

APPENDIX B

PUBLIC INVOLVEMENT THROUGH ROUNDTABLE DIALOGUE

PUBLIC INVOLVEMENT THROUGH ROUNDTABLE DIALOGUE

Public involvement is critical to successful development and transfer of remedial technologies. The public includes potential partners in private industry, academia, and other federal agencies, as well as other citizen groups concerned about the progress of environmental cleanup and management. As technologies are developed, the public must be updated on technology developments. A method to actively involve key stakeholders to explore issues relative to innovative technology development and implementation recently was demonstrated.

A televised public debate on the risk of new technologies using a format based on the Medical University of South Carolina's "Crossroads of Humanity" series was held on November 19, 1994, in Idaho Falls, Idaho. A hypothetical scenario was used to explore the risks and benefits of using new technologies to solve environmental problems. By using the Socratic dialogue format, a cross-section of experts dramatically presented the perspectives of real people confronting real problems.

There were 12 panel members with the dialogue moderated by Roy Eiguren, an environmental attorney from Boise, Idaho. A broad diversity of perspectives was represented by the panel experts. Panelists included: Leo Duffy, former DOE Assistant Secretary for Environmental Restoration and Waste Management; James McClure, former U.S. senator from Idaho; Linda Milam, mayor of Idaho Falls; Lew Rodriguez, regional manager of the Idaho Migrant Council; Brett Hayball, tribal environmental coordinator for the Shoshone-Bannock Tribes; Toby Michelena, State of Washington Oversight-Hanford Tank Waste Remediation System; Jim Yost, director of public affairs for the Idaho Farm Bureau; Dr. Richard Belsey, member of Physicians for Social Responsibility; Jonathan Stoke, member of the Sierra Club; Ray Burstedt, senior business consultant for the Idaho Small Business Development Center; Jim Cummings, program analyst for the Environmental Protection Agency; and Pat Bean, reporter for the Standard Examiner in Ogden, Utah.

The panelists addressed issues facing the fictional town of High Desert, including the spread of contaminants coming from a government buried waste site. The moderator presided over the discussions and would set the stage for each act of the Socratic dialogue. The discussions addressed many different alternatives to the risks associated with the threat of environmental contamination and elicited responses across all political, economic, social, and scientific views. Some of the issues and comments raised during the discussion included the following:

- Stakeholders need to be informed of all activities that may have an environmental or economic impact on their lives
- Stakeholders must have the opportunity to evaluate alternatives and participate in the decision-making process
- A relationship with regulators must be fostered to achieve effective oversight and cleanup
- Many difficulties arise in deciding what is an acceptable risk
- The panel was generally supportive of innovative technologies.

This roundtable discussion was the first of its kind at a national laboratory and will be featured on Public Broadcasting Service television stations nationwide. A second roundtable is scheduled for late August and will be centered around using buried waste specific technologies for remediation.

This type of activity can benefit other environmental remediation programs by reinforcing the need and desire for early stakeholder involvement in the environmental decision-making process. The roundtable provides a model for other sites to involve interested stakeholders.

A televised roundtable discussion was the first of its kind at a national laboratory. Associated Press photo.