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Office of Environmental Management

Office of Technology Development

Mixed Waste Landfill Integrated Demonstration

Technology Summary

February 1994

MIXED WASTE LANDFILL INTEGRATED DEMONSTRATION

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OFFICE OF TECHNOLOGY DEVELOPMENT OVERVIEW

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

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

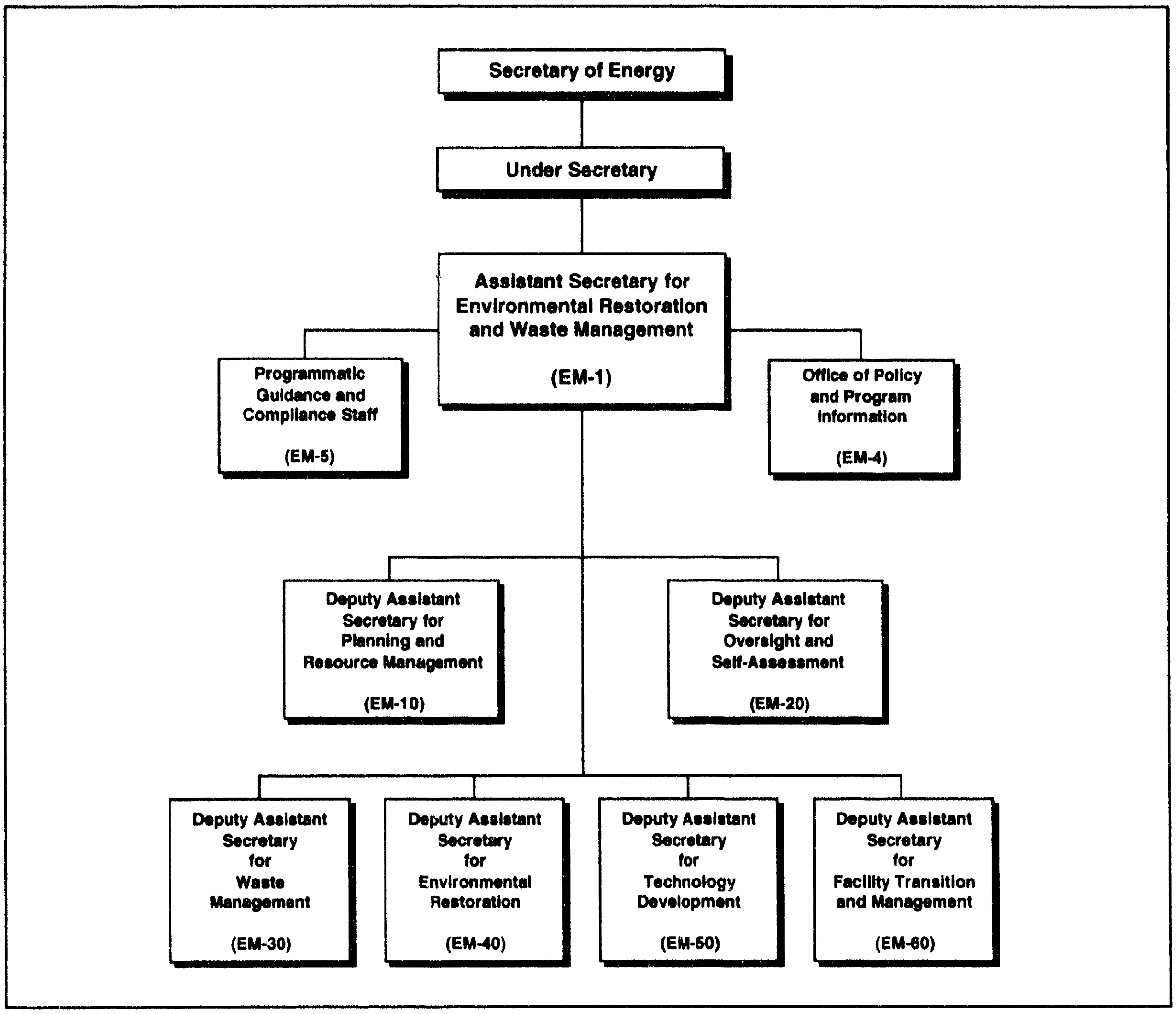

Figure A. DOE Organizational Structure as of June 1993.

In an effort to focus resources and address opportunities, EM-50 has developed **Integrated Programs** (IP) and **Integrated Demonstrations (ID)**. An *Integrated Program* focuses on technologies to solve a specific aspect of a waste management or environmental problem and it can be either unique to a site or common to many sites. An Integrated Program supports applied research to develop innovative technologies in key application areas organized around specific activities required in each stage of the remediation process (e.g., characterization, treatment, and disposal).

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

The Mixed Waste Landfill Integrated Demonstration (the subject of this report) is part of EM-551, Environmental Restoration Development, Testing, and Evaluation Division of EM-55.

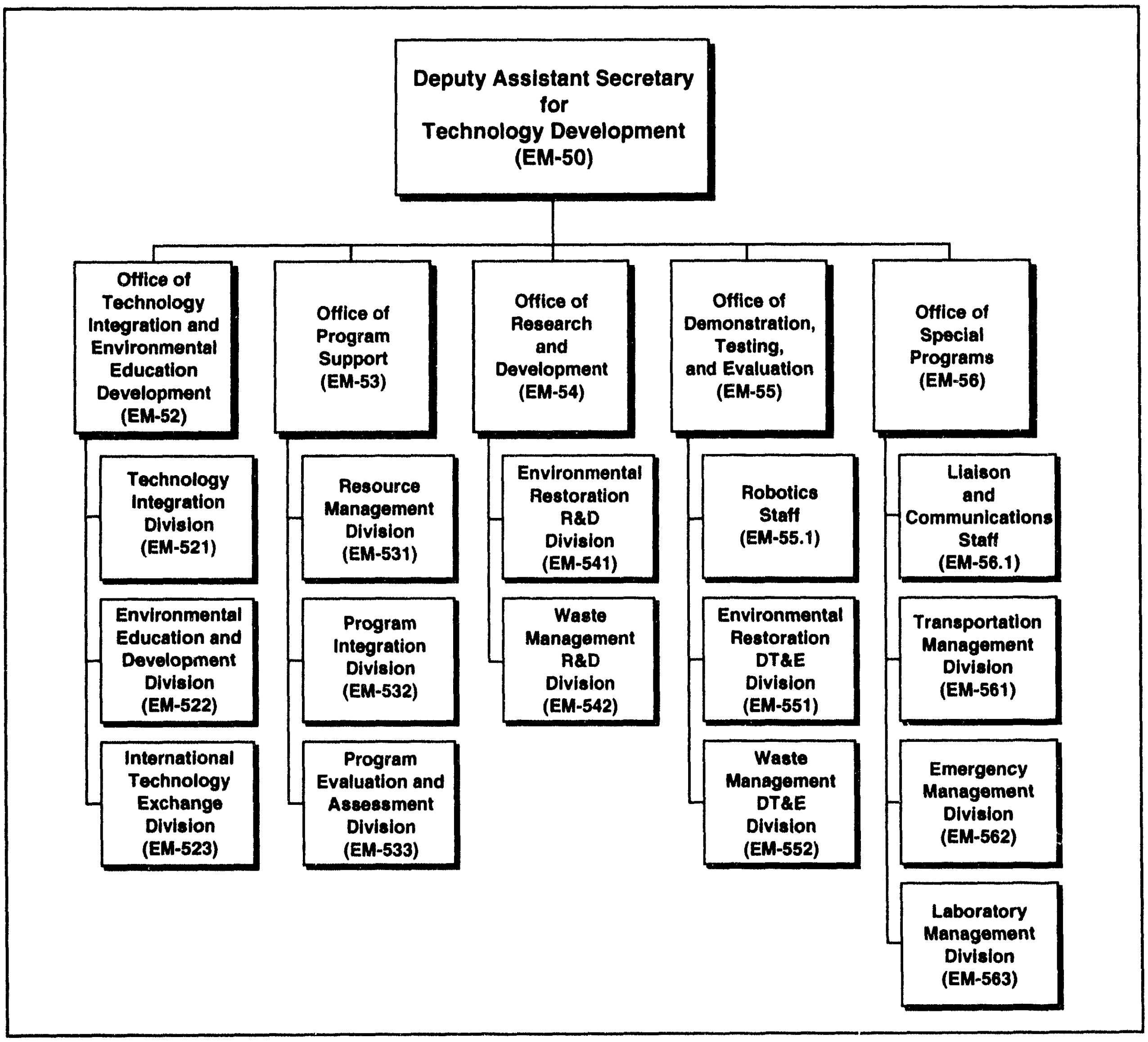

Figure B. Office of Technology Development Organizational Structure as of June 1993.

MIXED WASTE LANDFILL INTEGRATED DEMONSTRATION OVERVIEW

The mission of the Mixed Waste Landfill Integrated Demonstration (MWLID) is to demonstrate, in contaminated sites, new technologies for clean-up of chemical and mixed waste landfills that are representative of many sites throughout the DOE Complex and the nation (see Figure C). When implemented, these new technologies promise to characterize and remediate the contaminated landfill sites across the country that resulted from past waste disposal practices. Characterization and remediation technologies are aimed at making clean-up less expensive, safer, and more effective than current techniques. This will be done by emphasizing in-situ technologies. Most important, MWLID's success will be shared with other Federal, state, and local governments, and private companies that face the important task of waste site remediation. MWLID will demonstrate technologies at two existing landfills. Sandia National Laboratories' Chemical Waste Landfill received hazardous (chemical) waste from the Laboratory from 1962 to 1985, and the Mixed-Waste Landfill received hazardous and radioactive wastes (mixed wastes) over a twenty-nine year period (1959-1988) from various Sandia nuclear research programs. Both landfills are now closed. Originally, however, the sites were selected because of Albuquerque's arid climate and the thick layer of alluvial deposits that overlay groundwater approximately 480 feet below the landfills. This thick layer of "dry" soils, gravel, and clays promised to be a natural barrier between the landfills and groundwater.

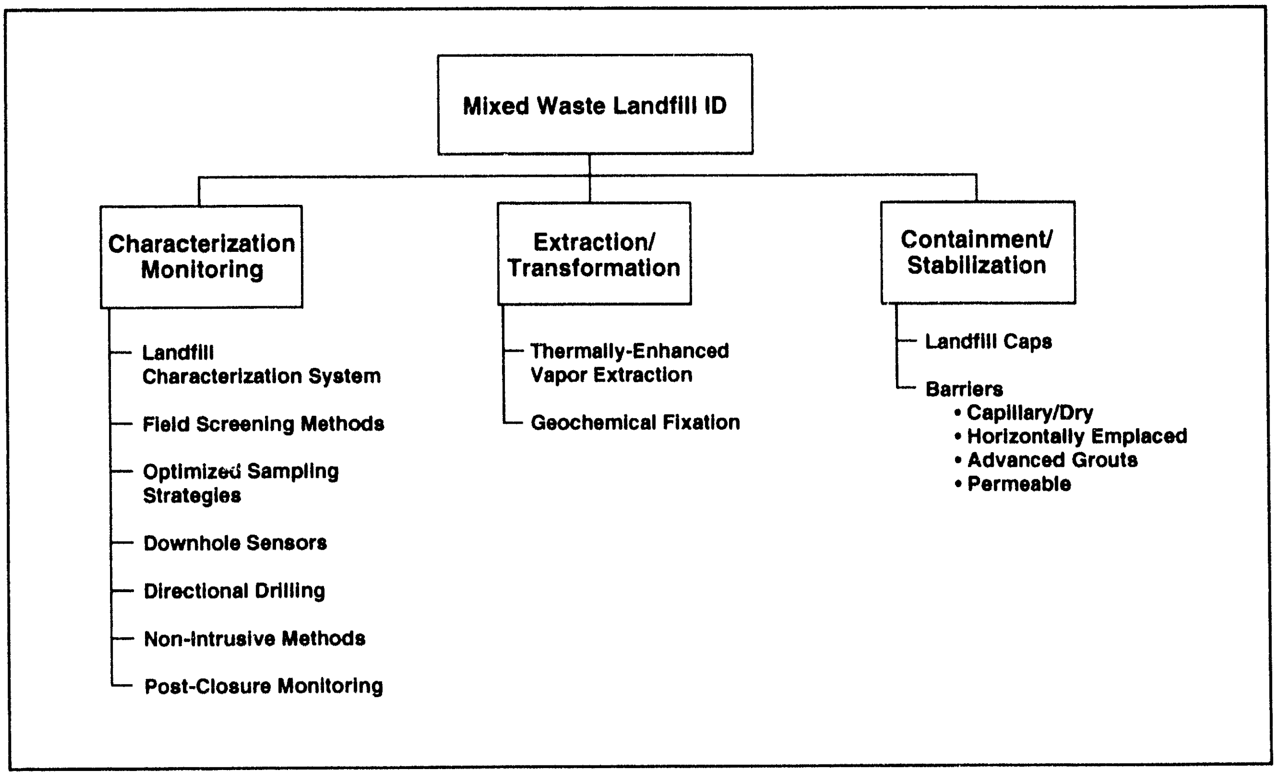

Figure C. Mixed Waste Landfill Integrated Demonstration Technologies.

SELECTED ACCOMPLISHMENTS

- Successfully assisted in identifying a previously undetected plume of chromium and other metals at Sandia's now-closed Chemical Waste Landfill in Tech Area III through a field demonstration of sonic drilling technology.

- Placed four landfill caps at Hill Air Force Base to contain contaminants in landfills. The operation involved extensive instrumentation to determine moisture movement and to determine effectiveness of landfill caps to prevent migration of contaminants into the surrounding environment.

- Demonstrated SEAMIST™ hole liner, which allows low-cost, concise placement of characterization sensors, at the mixed waste landfill site and Tucson airport and transferred the technology to commercial company.

- Demonstrated downhole sensor technology in conjunction with directionally drilled holes lined by SEAMIST™ plastic liner.

- Demonstrated a towed array magnetometer as a non-intrusive technique for locating buried waste containers and transferred the technology to commercial industry.

- Demonstrated the downhole X-ray fluorescence (XRF) device in a horizontal, SEAMIST™ lined borehole during a cold test.

- Demonstrated a downhole drilling monitoring system to integrate radiation detection hardware during drilling.

- Demonstrated electromagnetic imaging, and in the process of transferring it to commercial industry.

Characterization Technologies

Section 1.0

1.1 LANDFILL CHARACTERIZATION SYSTEM

TASK DESCRIPTION

The Landfill Characterization System (LCS) is a method to characterize metal and mixed waste contaminant sources and their migration beneath landfills (see Figure 1.1). The emphasis of the system is on minimally intrusive technologies and downhole sensors where possible. The system is to utilize the best of available and emerging technologies with minimal development work.

The LCS is envisioned to be a cradle-to-grave system for landfill characterization, with compatible, complementary, and integrated technologies. Cost and time savings will result. The LCS may include commercially-available technologies, as well as those being demonstrated individually as part of the MWLID. The LCS consists of four separate subsystems: pre-screening technologies, drilling technologies, on-site field laboratory analysis, and borehole technologies. In some instances, technologies may be combined to produce hybrid systems, such as directional boring and downhole sensing. The LCS approach will employ nonintrusive characterization, safer directionally drilled access, measurement while drilling, an optimal sampling strategy, a membrane liner, in-situ sensors, and an on-site laboratory. As long-term monitoring activities become increasingly emphasized, the LCS will transition to a Landfill Characterization and Monitoring System (LCMS).

TECHNOLOGY NEEDS

A systems approach for characterization of metal contamination ensures that the technologies are directed toward solving the problem at hand. By considering the entire system, the technologies are more likely to be practical and useful in the field. As technologies and opportunities emerge, they can be incorporated into the system. Similar technologies can be evaluated side-by-side in the system.

ACCOMPLISHMENTS

In 1993, the LCS was conceptualized as the following closely integrated subsystems:

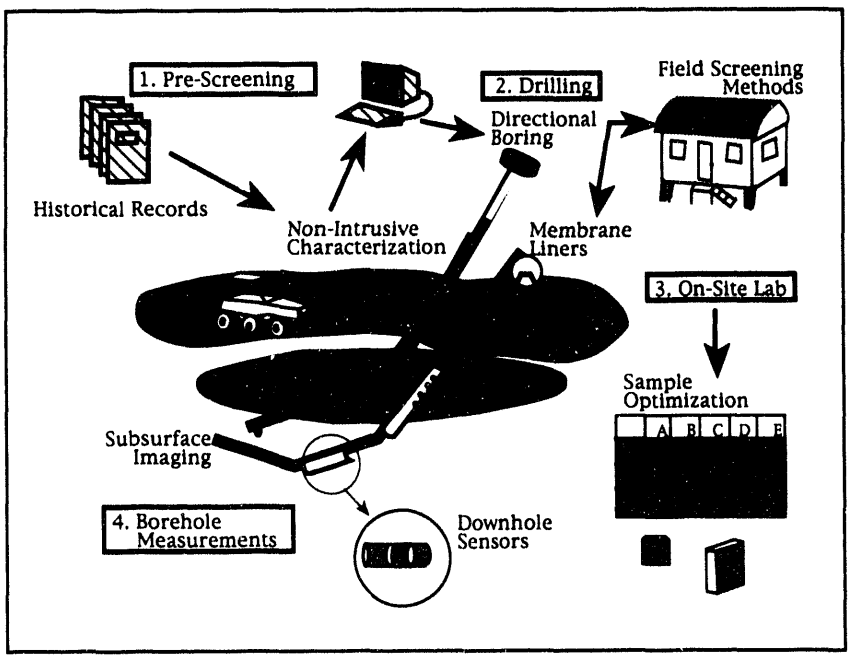

Figure 1.1. Landfill Characterization System.

- pre-screening methods;
- drilling;
- field screening laboratory; and
- borehole sensors.

These subsystems were field demonstrated during FY93, primarily at Sandia's Chemical Waste Landfill (CWL). Some technologies were also being demonstrated at the Kirtland Air Force Base RB-11 Landfill as the fiscal year drew to a close.

In April 1993, resonant sonic drilling was used to bore two parallel shallow boreholes, 150 feet long and at 15° to the horizontal, beneath the 60's pits at the CWL. This drilling was combined with near-real-time, on-site field screening for metals analysis by X-ray fluorescence and stripping voltammetry. The field screening effort discovered a major source of chromium contamination, previously unknown. After completion of drilling, including casing, the SEAMIST membrane instrumentation and sampling system was installed for vapor phase sampling. During the summer, these two holes, as well as three previously drilled holes at the Unlined Chromic Acid Pit (UNCAP) were used to demonstrate and test various downhole sensors (e.g., cross-borehole and surface-to-borehole electromagnetic imaging; cross-borehole seismic imaging; downhole X-ray fluorescence; and microgravity). In September, the magnetometer towed array was successfully field demonstrated at the RB-11 site, and a calibration test was carried out at the CWL. A surface-to-surface cased borehole using directional drilling technology was also successfully completed at RB-11.

A milestone report dealing with technical and economic evaluations of selected LCS technologies was completed at the end of FY93, and was the subject of an oral presentation at the ER '93 Conference in Augusta, Georgia (October, 1993).

COLLABORATION/TECHNOLOGY TRANSFER

This project involved collaboration with the following National Laboratories and commercial industries.

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1.2 FIELD SCREENING LABORATORY

TASK DESCRIPTION

The objective of this task is to develop a mobile field screening laboratory capable of high-quality, same-day metals and organic analysis of toxic, radioactive, or mixed waste environmental samples. The task intends to rapidly develop new methods to enhance and more fully utilize the capabilities of commercially available X-ray fluorescence (XRF) for metals analysis, and gas chromatograph with a mass spectrometer (GCMS) for volatile organic analysis of water and soil.

The XRF tool is a benchtop instrument that uses an X-ray tube to excite the soil. A dry soil sample is taken and sifted through a 10-mesh screen and analyzed. If any chrome is found, it is ground to 200-mesh and another analysis is conducted. Efforts are now being made to use thin films of ground powdered samples, which reduces the mass of the sample without reducing sensitivity. The GCMS is used for volatile organic analysis by taking a bulb of gas extracted from the soil. A small aliquot is sent into the gas chromatograph (GC) for analysis, resulting in a chromatograph. Methods have been developed to achieve better detection limits, to monitor well gas sampling (see Figure 1.2).

TECHNOLOGY NEEDS

There are both cost- and time-saving advantages of operating a field screening lab rather than sending samples off-site for analysis. Cost savings are even greater with radioactive samples. Results obtained in near-real time can be input immediately into the sampling optimization methodology to determine the optimal location and number of additional samples. This can potentially reduce the total number of samples required to adequately delineate the contaminant plume and speed up the characterization effort. The currently accepted alternative is to send samples to an analytical laboratory for analysis. This requires a more lengthy chain of custody to be followed, and typically, weeks pass before results are available. Often, characterization activities have been concluded before the first analytical result is obtained. A characterization effort could be

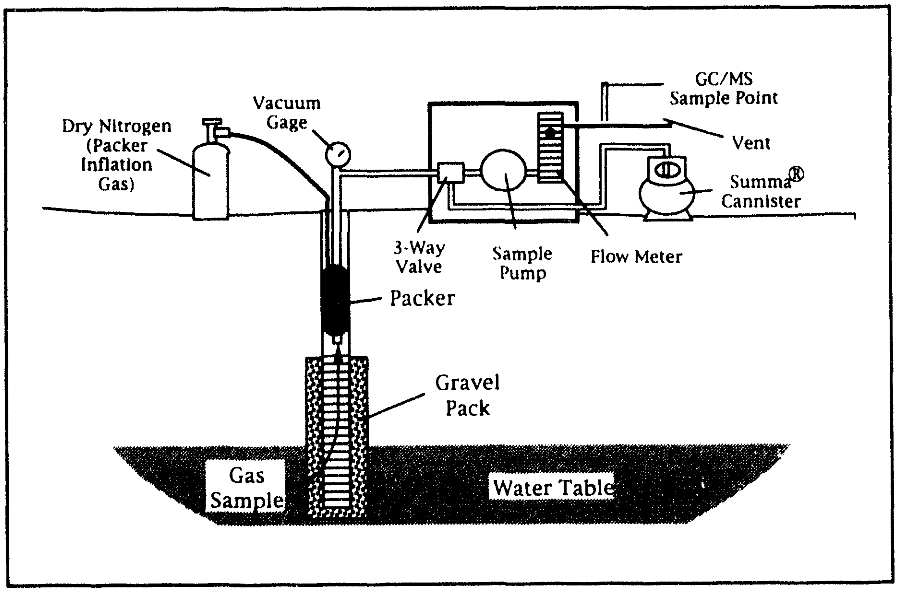

Figure 1.2. Monitor Well Sampling.

completed, and the analytical results weeks later indicate that the plume was missed and the effort must be repeated. The long delay in obtaining results from the analytical laboratory also has an impact on health and safety. Overly conservative personal protection equipment may be used because the extent and nature of the contamination is unknown. This drives up the cost and slows down the characterization effort.

ACCOMPLISHMENTS

New methods for the GCMS have greatly improved detection limits, for both soil gas and water. For soil gas, the entire content of a gas sample bulb is purged onto a trap, which is then thermally desorbed onto the GC column for analysis. Water samples are also purged onto a similar trap and thermally desorbed in the same manner. The similarity in the soil gas and water analysis allows the same instrument to be used for both analyses with minimal changes in the instruments operation parameters. One round of monitor well gas sampling has been completed and the second round is in progress.

The thin-film XRF methods are now available and a training session on the procedures will begin soon.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with the following commercial industries.

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1.3 OPTIMIZATION OF SAMPLING STRATEGIES

TASK DESCRIPTION

The primary objective of this project is to provide an approach for guiding sample placement for contaminant delineation. This approach must be capable of assisting in siting vertical soil boreholes, directionally drilled boreholes, and sampling locations along such boreholes. It should include an easy-to-use data management system that allows new data to be integrated with old, and should be visually displayed with useful graphics on computer screens (see Figure 1.3). Such graphics could include maps of contaminant extent, subsurface "cuts" that show contamination location relative to important geological features, etc. It must quantitate contaminated soil and water, and should also provide estimates of the errors associated with these measurements. The data can be used for determining when enough samples have been taken to accurately delineate contamination.

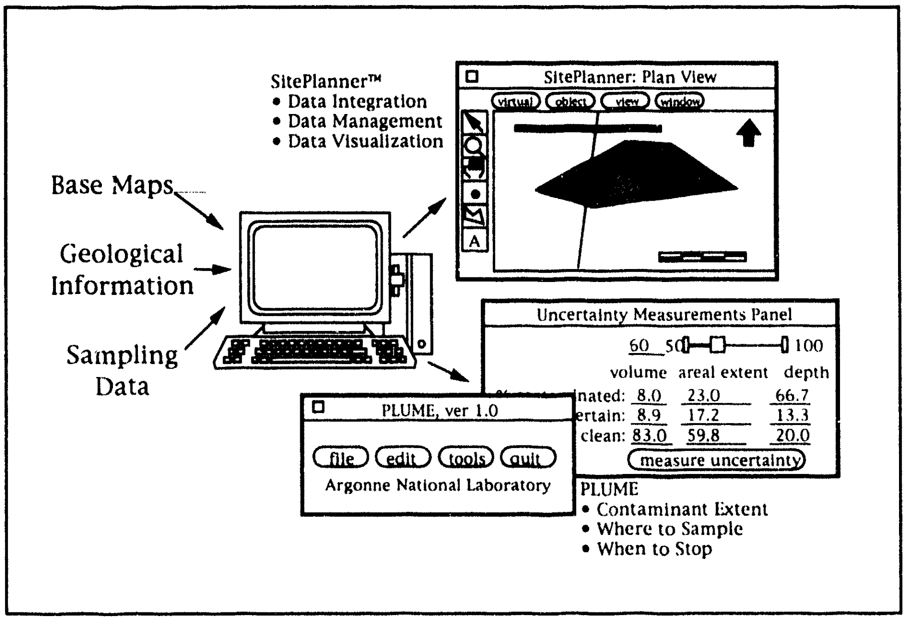

Figure 1.3. Adaptive Sampling Strategy Support.

This project adopts a dual approach to the sampling strategy problem. First, it uses a state-of-the-art object-oriented database system that was specifically designed for site assessment work to integrate, manage, and display site characterization data as it is being generated. This package is called SitePlanner, and was developed by ConSolve, Inc. SitePlanner provides site characterization technical staff with an understanding of their site data as quickly as possible. Coupled with SitePlanner is PLUME, an interactive software package developed at Argonne National Laboratory. PLUME uses advanced statistical procedures to merge "soft" site data with "hard" sample results to form images of contamination location. It also provides quantitative measures of the potential benefits to be gained from additional sampling, and indicates where the best new sampling locations are.

This approach has several advantages over traditional methodologies. In terms of data management and display, SitePlanner provides specialized graphics that are dynamically tied to underlying data. As new data are generated and included in the database, graphics change to reflect the new information. In contrast, traditional Geographical Information Systems (GISs) are limited in the types of graphics they can produce. In the past, specialized graphics packages have not included data management capabilities. SitePlanner was designed as a mouse and menu-driven system that is relatively easy to learn and apply. Traditional GISs and Relational Database Systems (RDBSs) require specialized computer experts to be effective, and are usually not available to the technical staff actually involved with site characterization work.

In terms of data analysis, PLUME readily uses soft data along with hard information to guide sampling strategy selection. This is particularly important for sites in the initial phases of site characterization, when the amount of soft information available typically overwhelms any existing hard sampling results. This capability makes it uniquely different from past sampling strategy selection methodologies. PLUME was designed to address the total sampling strategy problem, including measures of contaminant extent, measures of benefits to be expected from additional sampling, and recommendations about additional sampling locations. Past approaches only addressed one or two of these issues. PLUME has been designed to work tightly with SitePlanner, using a mouse and menu interface. This also makes it easy to use and readily accessible to site characterization technical staff.

TECHNOLOGY NEEDS

Site characterization is an extremely expensive process that typically involves merging information gleaned from historical records, results from field screening sensors, and data generated by laboratory sample analyses. A key step in the characterization of hazardous wastes at DOE sites is determining the extent of contamination. The proper number and placement of sampling locations is required to both minimize characterization costs, and guarantee that contamination extent can be estimated with reasonable confidence. Because "soft" information (i.e., historical records, computer modelling results, past experience, etc.) for a site are usually just as important as "hard" laboratory results, the approach taken must include a quantitative way of accounting for both hard and soft site data.

ACCOMPLISHMENTS

PLUME and SitePlanner were used to delineate subsurface chromic acid contamination at the Chemical Waste Landfill, Sandia National Laboratories. Retrospective studies of characterization efforts at the UNCAP indicate that substantial cost savings could have been realized if an adaptive sampling program (field screening technologies, SitePlanner and PLUME) had been used at this site from the outset. PLUME is currently undergoing commercialization through a Cooperative Research and Development Agreement (CRADA) negotiated with ConSolve, Inc. Future work through the MWLID includes linking these approaches to risk assessment methodologies at Sandia's Mixed Waste Landfill, and implementing a pilot adaptive sampling program at RB-11, a mixed waste site belonging to Kirtland Air Force Base (KAFB).

COLLABORATION/TECHNOLOGY TRANSFER

The software is being incorporated into the Sandia Environmental Decision Support System. PLUME software will be commercialized in 1994 by ConSolve, Inc. Site Planner is currently available commercially from ConSolve, Inc.

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1.4 INVERTING MEMBRANE BOREHOLE INSTRUMENTATION TECHNIQUES (SEAMIST™)

TASK DESCRIPTION

SEAMIST™ is an instrumentation and fluid sampler emplacement technique designed for in-situ characterization and monitoring. It uses an inverting, pneumatically-deployed tubular membrane (impermeable material) to deploy sensors and/or samplers in boreholes or to tow instruments downhole in a clean, stable borehole environment (see Figure 1.4).

The membrane, made of coated fabric or synthetic film, is forced from a holding canister by air pressure into a drilled or punched well. The membrane descends, everts, and presses against the hole wall, providing wall support and the effect of a continuous packer. After emplacement, the entire hole wall is sealed, thus preventing ventilation of the pore space or circulation of pore water in the well. The membrane can be retrieved from the hole.

Permanent installation of the membrane is possible by filling the membrane with grout after emplacement. Semi-permanent installation can be accomplished by filling the membrane with sand after emplacement, which can be removed by vacuuming where membrane retrieval is desired.

Monitoring instruments and pore fluid sampling devices are placed on the outer surface of the membrane, in contact with the hole wall. The membrane isolates each measurement location. Emplacement has been demonstrated for vertical, horizontal, and crooked or partially obstructed holes. Instruments or samplers are not dragged along the hole wall at any time.

The membrane can be used to perform vadose zone pore and fracture fluid sampling using absorbent pads. Electrical resistance measurements inside the pads indicate moisture uptake. By attaching an array of absorbent pads to the membrane, high spatial resolution of the contaminant distribution is possible.

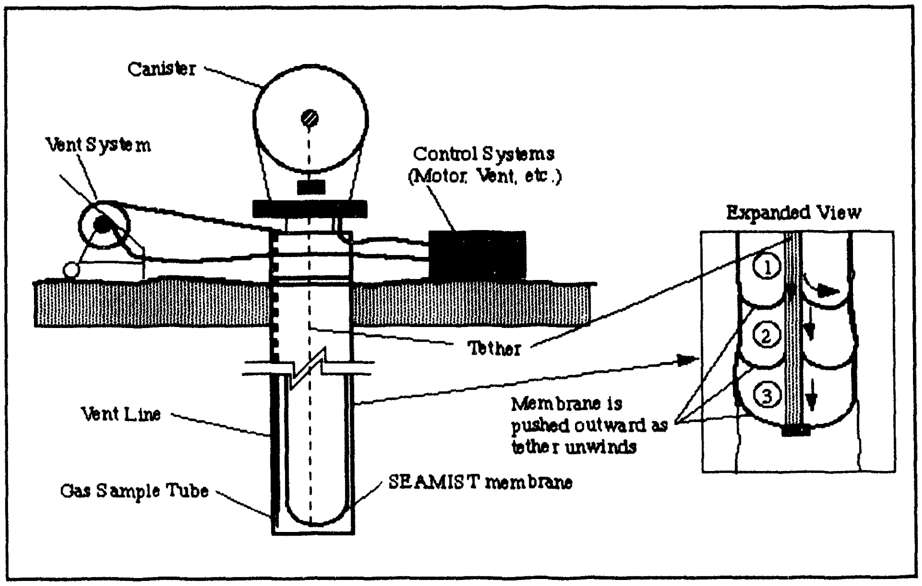

Figure 1.4. SEAMIST™

Extraction of soil gas samples from a downhole can be accomplished via tubes to surface sample collectors. Getters (such as activated charcoal adsorbers) can also be attached to the membrane surface to adsorb contaminants. A hybrid concept is to pull a gas sample through a filter positioned at the sampling point.

Additional classes of sensors and/or sampler instruments can be integrated with the SEAMIST deployment system. These include thermocouple psychrometers, gypsum blocks, pressure transducers, temperature sensors, calorimetric indicators, and hydrocarbon-sensitive adsorbing resistors.

TECHNOLOGY NEEDS

Many of the problems with conventional vadose zone monitoring techniques are eliminated or minimized by the SEAMIST™ design. Because it is customizable, retrievable, reusable, and leaves the borehole clean, SEAMIST saves not only time, but also money in drilling costs, tool rehabilitation (rather than replacement and upgrades), and waste stream disposal. It also minimizes or eliminates problems that conventional systems experience, such as retrieval and repair of buried instrumentation, cross-contamination of samples, single-point sampling with screened wells, and borehole stability. The system is ideal for field work, as the device is easily handled and transported. A small unit can fit into the trunk of a car and installation is fast: emplacement in a 100-foot borehole can take less than five minutes.

ACCOMPLISHMENTS

- Tritium Plume Monitoring. Two systems installed at Lawrence Livermore National Laboratory (LLNL) in 1991 are tracking the movement/concentrations of a tritiated water plume (vapor and liquid water sampling) to 40-ft depths.
- Carbon Tetrachloride Monitoring. Two emplacement systems with disposable membrane liners are in use at Hanford for carbon tetrachloride plume monitoring.
- Fracture Flow Mapping and Rate Measurement. Membranes coated with liquid-indicating and wicking layers were used to map and measure brine flows underground at the Waste Isolation Pilot Plant (WIPP).
- Tritium and VOC Sampling. The SEAMIST™ system transported vapor sampling tubes and adsorbent collectors 230 feet horizontally beneath an old radwaste landfill at Los Alamos National Laboratory (LANL).
- Mixed Waste Landfill Demonstrations. Transported logging tools and cameras in horizontal boreholes of up to 230-ft length and 1.75 to 4.0-in diameters. Performed gas sampling and permeability measurements in two vertical boreholes of 11.5-in diameter and 110-ft depth immediately after auguring in SNL's CWL. Installed three borehole liners of 110-ft length.
- Emplaced, operated and removed a vapor sampling membrane in the CWL 60's pit horizontal borehole that incorporated seven sampling points on 170' length, 4" diameter membrane.
- Emplaced, operated (~2 weeks) and removed SEAMIST membranes incorporating physical process and chemical sensors in 110' deep borehole at CWL.

- Standard SEAMIST vapor sampling systems were integrated with surface-based VOC analysis systems (automated/unattended GC and UV fluorometer).

- Emplaced and currently operating a 400' long 4.5" diameter vapor sampling membrane in the KAFB RB-11 landfill horizontal borehole.

- Vapor Sampling/Permeability Measurements. Three membranes were instrumented and installed at Savannah River Site (SRS) in July 1992 for soil vapor, vapor pressure, and permeability measurements. Maximum depth was 130 ft, with 10 sampling elevations per membrane.

- Neutron Logging Tool Transport. The membrane towed a 3-lb neutron moisture logging tool in horizontal boreholes. Typically, four 4.5-inch diameter holes (200-250 feet) were logged in one day, with data taken every 2 feet.

- Vapor Sampling. A vapor sampling system was installed to 90-foot depths for long-term monitoring.

- Borehole Liners. SEAMIST™ liners were installed to support/seal holes while a long-term monitoring system is designed. Hole diameter was 8.5 inches and depths were 80-100 feet.

- High-Pressure Borehole Liners. Two Kevlar-reinforced membranes were installed to a depth of 155 feet, then filled with water inside cased walls to prevent collapse of PVC casing during remediation experiments.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with:

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The geologic patent for SEAMIST™ was sold to Eastman Cherrington Environmental, Inc. for commercial use in 1993.

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1.5 HYBRID DIRECTIONAL BORING AND HORIZONTAL LOGGING

TASK DESCRIPTION

The objective of this task is to develop the capability to emplace usable cased/screened directional boreholes in desired locations at environmental sites cost-effectively.

Hybrid directional boring machinery capable of exerting hydraulic thrust forces greater than 80,000 pounds are used to push directional boring heads into the earth. Directional control is obtained by proper positioning of the non-symmetric face of the boring head. Slow rotation of the boring head cuts and compacts the geologic material. Pushing a non-rotating boring head causes directional change. Machinery is capable of initiating a borehole at ground or shallow pit level, steering down to the desired depth, continuing horizontally at that depth, and then steering back to the surface. Casing and/or screen material can be installed in the borehole by attaching it to the drill rod being retrieved.

TECHNOLOGY NEEDS

This technology is well suited to provide quality access beneath landfills, buildings, and buried tanks as it uses minimal fluids for drilling, and since cuttings are compacted in the borehole, very little material is returned to the surface. It is estimated to cost between $25-75 per foot compared to over $300 for larger conventional rigs.

ACCOMPLISHMENTS

- Developed a new prototype drilling machine with larger hydraulic thrusting capacity, (minimum of 80,000 pounds) and with the capabilities to rotate while thrusting and do limited drilling in rock.
- Developed an on-board tracking system to give drill bit location during drilling, thereby enabling penetration at depths greater than 15 feet.
- Directionally drilled pilot hole using a redesigned drill bit in difficult sand/cobble formations at Sandia National Laboratories' CWL site.
- Successfully installed a horizontal well using the new prototype machine at Savannah River for the use of radio frequency heating, accelerating remediation of a VOC-contaminated zone (FY 92).
- Successfully installed a horizontal well using the testbed prototype under the RB-11 site at Kirtland Air Force Base. The well will initially be used for vapor sampling and gamma spectroscopy studies by SEAMIST and Pacific Northwest Laboratory (PNL) researchers.

COLLABORATION/TECHNOLOGY TRANSFER

This project is being jointly developed with Charles Machinery Works; commercialization of the technology will be completed in 1994.

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1.6 INTEGRATED GEOPHYSICS PROGRAM

TASK DESCRIPTION

The objective of this task is to demonstrate that an integrated program of surface geophysics can effectively address the need for non-intrusive characterization of mixed waste landfill sites (see Figure 1.6). Qualitative descriptions of the test sites and their contents suggest that a number of established geophysical methods may be applicable. Using multiple testing techniques, this approach is designed to make characterization efforts more accurate and more complete by integrating data from multiple techniques, e.g. by integrating the data from the magnetic gradiometer technique with the data from the complex resistivity method.

The use of a particular geophysical technique depends primarily upon the target of interest, the geology of the survey area, and the possible interference from surrounding objects. Because each technique measures different physical parameters and is appropriate for different situations, an integrated approach offers data and interpretation not attainable by using a single technique. A brief description of each geophysical technique to be demonstrated in this program follows.

The magnetic gradiometer technique measures variations in the intensity of the earth's magnetic field. Ferromagnetic objects affect the earth's magnetic field and can produce a magnetic anomaly. With the assumption that many metal waste storage drums and metallic debris exist within the confines of a pit, a minimum boundary can be quickly determined.

Certain chemicals react with clays to produce substances that provide a characteristic response to the complex galvanic resistivity method. In addition to possibly identifying broad classes of wastes in the pits, the complex resistivity response may delineate the chemical interaction boundary and, thus, the waste pit boundaries. Naturally occurring voltage, generally termed a spontaneous potential (SP), frequently builds up at the boundaries of a waste pit, due to the difference in chemical composition and solution pressure of the material on each side of the boundary. A simple map of the voltage measured over disturbed and undisturbed areas can be used to define pit boundaries.

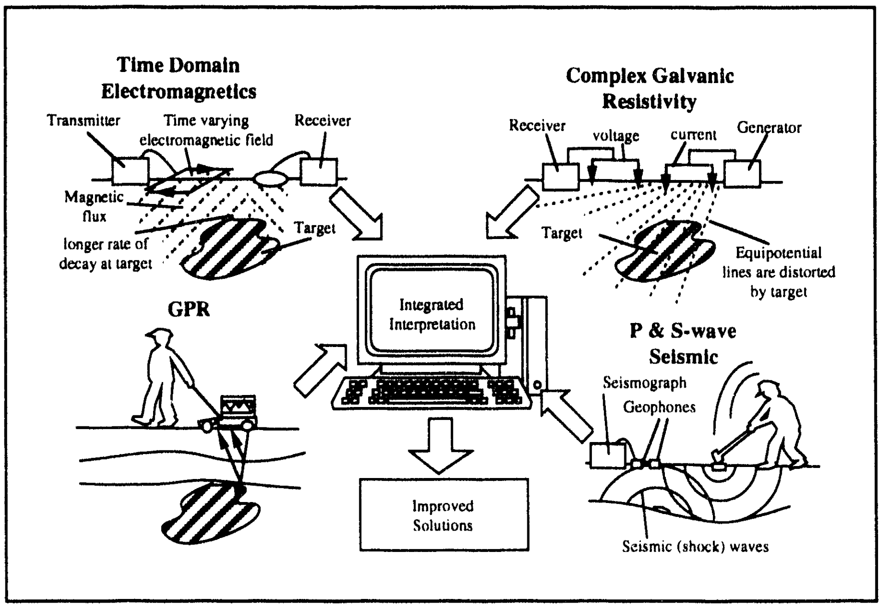

Figure 1.6. Integrated Geophysics.

Under favorable transmissivity circumstances, ground-penetrating radar (GPR) profiles may indicate pit boundaries because of a propagation contrast in the disturbed area compared with undisturbed soil. This may be attributed to a moisture contrast or mechanical factors related to soil disturbance. In this manner, GPR measurements may yield information on the volume of wastes within a pit.

The waste materials within the pits (such as metals, metal salts, and other chemicals) have a profound effect on the conductivity of the pit in contrast to undisturbed ground. Time-domain electromagnetic (TDEM) methods can be used to map conductivity/resistivity contrasts. In addition to delimiting the pit area, the conductivity data can provide insights to the type and quantity of material in the pits. A conductive plume that is migrating beyond the pit boundary toward a borehole can be readily detected with this technique.

Shear-wave (S-wave) refraction and compressional-wave (P-wave) reflection seismic surveys can detect seismic wave transmission differences expected between disturbed and undisturbed material. Variations in the phase, amplitude, frequency, and velocity of horizontally polarized shear waves are indicative of changes within the subsurface. The locations of these seismic differences can help differentiate pit boundaries, and can also help determine the volume of waste within a particular pit.

TECHNOLOGY NEEDS

Surface geophysical surveys are routinely used in many groundwater, geotechnical, and waste-site characterization projects. Often, however, only a few techniques are used because of limited experience, ill-perceived notions of a certain technique's usefulness, or cost and schedule considerations. An integrated approach using pertinent geophysical techniques offers data and interpretations not attainable by a single technique. To successfully integrate the data from various geophysical techniques, considerable experience is necessary to ensure that data of the highest quality are acquired at suitable spacings. Once sufficient high-quality data are acquired, modelling and an integrated interpretation of the data can be conducted. This integrated approach offers solutions that encompass numerous physical property contrasts, and is therefore more reliable than interpretations from a single geophysical technique.

ACCOMPLISHMENTS

- Seismic geophysical surveys were conducted at the MWLID test site at Sandia National Laboratories/New Mexico in Albuquerque.
- Locations of the known chromic acid and organics pits were interpreted at or near their historical boundaries, unknown pits were identified, and areas of disturbance possibly related to contaminants were interpreted outside the boundaries of both the known and unknown pits. Rudimentary waste types were identified and modelled where appropriate, and anomalies from recent activities were identified and discounted from further analyses.
- Pit boundaries and basic geometries (horizontal and vertical extent) were identified to less than 3 feet through integrated interpretation of complex galvanic resistivity, GPR, and S-wave seismic data.

- Indication of metallic debris within the identified pits was accomplished through combined interpretation of all the data sets; the presence of nonmetallic debris was interpreted if an anomaly was indicated in the S-wave seismic, P-wave seismic, or GPR data but was not evident in the complex galvanic resistivity or TDEM data.

For further information, please contact:

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RUST Geotech Inc.
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1.7 ADVANCED IN SITU MOISTURE LOGGING SYSTEM

TASK DESCRIPTION

The objective of this task is to demonstrate and evaluate a self-contained nuclear moisture/density probe in directionally drilled access tubing (see Figure 1.7).

The neutron source/detector consists of an americium/beryllium combination (10 mCi). The source and detector are located in close proximity to each other, and the probe counts thermalized "slow" neutrons that have contacted hydrogen atoms. The Troxler count ratio is generally linear with respect to percent moisture. Its configuration allows for quantification of the moisture content to within plus or minus 2% volumetric water content when calibrated to a given soil, and has an approximate radius of influence of about 30 cm. The gamma source, for measuring soil density, is an 8 mCi cesium-137 configuration.

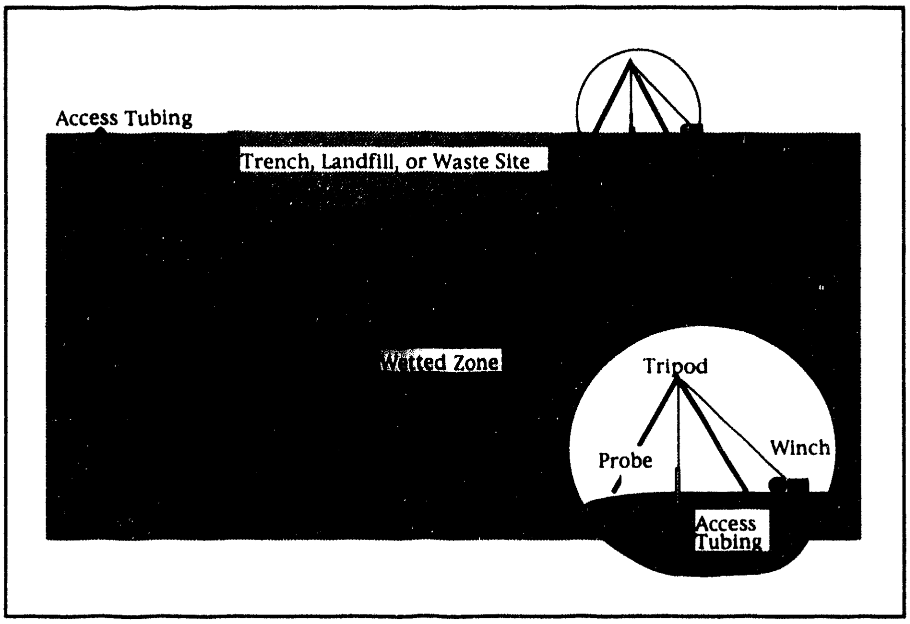

Figure 1.7. Moisture Logging.

The conventional means of deploying such a probe is to lower a logging tool down an access tube to a depth ranging from several meters to tens of meters. The electronics to operate and process data from the probe are located in a housing that sits at the top of the access casing.

The cable used to lower the probe down the access tube serves as both support cabling and electronic communications. The increasing noise (background signal) may impair the data quality with increasing length of the cable; therefore, a practical limitation on hole depth exists.

The new Troxler probe is self-contained. In other words, the electronics required to take a reading and to program subsequent readings of moisture content and soil density are contained within the housing of the device itself. The probe is drawn through an access tube via a support cable and requires no electronic communications to the top of the casing; therefore, length of the access tubing is not prohibitive, and long horizontal tubes may be used if a delivery system is engineered properly. The proposed choice for a delivery system is to employ a constant velocity winch, or one which can be hooked up to a data logger or laptop computer to record cable take-up rate and time and/or length. Such a system has just become available from Mount Sopris Instrument Co. Inc., Golden, CO. Other devices exist to monitor in-situ moisture content and soil density, but are general point source devices.

The advantage of a downhole logging device is that continuous data collection along the length of the access tubing allows for greater spatial coverage. With the advent of the horizontal/directional drilling technologies, the application of the downhole self-contained monitoring devices becomes significantly enhanced. In addition, information from downhole logging devices is essential in evaluating the performance of such remedial alternatives as capping or soil venting strategies, and as input to risk assessment modelling methodologies. In deep vadose zone regimes, this type of device/monitoring system might be used in lieu of an expensive monitoring well. The tool being evaluated will provide a self-contained neutron/gamma moisture/density probe for use in vertical or horizontal access tubing of almost any length. The tool can be used at practically any waste site throughout the DOE Complex where moisture content and/or soil density data are needed, whether for leak detection or for performance of a facility.

TECHNOLOGY NEEDS

A self-contained nuclear moisture/density probe for use in directionally drilled access tubing beneath waste sites is needed for the purpose of leak/contaminant detection and post-closure monitoring.

ACCOMPLISHMENTS

- Evaluated and field tested the in-situ moisture logging system. Modifications to the system were made by the manufacturer, Troxler Electronics Laboratories, Inc., to ruggedize the system.
- Performed calibration experiments.
- Evaluated and procured a winch system.
- Constructed a field infiltration experiment.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with the following commercial industries:

Troxler Corp.
3008 Cornwallis Road
Research Triangle Pk, NC 27709
Contact: Rich Orban
Phone: (919) 549-8661

U.S. EPA
Environmental Monitoring Systems Laboratory
Las Vegas, NV 89193

For further information, please contact:

Robert Knowlton
Principal Investigator
Sandia National Laboratories
(505) 848-0425

George Allen
Technical Program Manager
Sandia National Laboratories
(505) 845-7015

1.8 ABSORPTIVE STRIPPING VOLTAMMETRY

TASK DESCRIPTION

The objective of this task is to develop and test the effectiveness of using absorptive stripping voltammetry (ASV) to determine the concentrations of leachable chromium, uranium, lead, cadmium, copper, nickel, zinc, and cobalt on soils/sediments, and to identify underground source terms and plumes underlying the chemical and mixed waste landfills (see Figure 1.8).

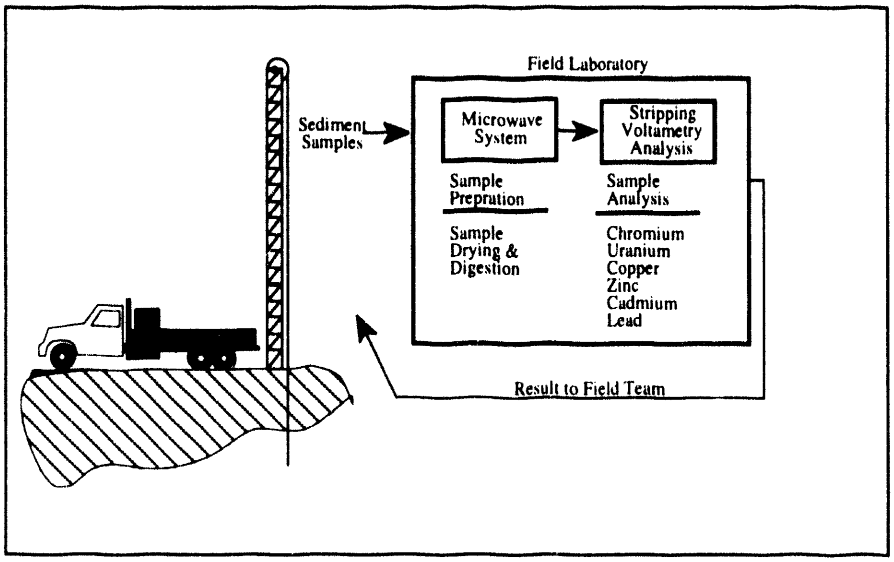

Figure 1.8. Absorptive Stripping Voltammetry.

Sediment samples are dried and digested in a microwave digestion system. Nitric acid solution is used as the leaching agent in the digestion process. Leachate (or digestate) solutions are diluted to 100 ml with distilled or deionized water and analyzed by stripping voltammetry for one or more of the elements of interest. Results are reported as ppm of dry weight for the metal of interest.

TECHNOLOGY NEEDS

Stripping voltammetry is well suited for field screening. The system is compact, requires minimal electricity (1 amp. at 120 volts-AC), and produces high-quality data in a short period of time. In fact, for trace metals, ASV is even a more sensitive technique than lab analysis. Significant cost savings are anticipated using ASV to support characterization activities. This cost savings arises from the ability to screen sediment samples concurrent with field teams' sampling activities. For example, the results from ASV can be used to identify when contamination has been encountered during drilling of boreholes. In addition, field screening efforts can be used during a removal action to help delineate when a cleanup level has been achieved for a contaminant of concern. Thus, cost savings occur because samples sent to the lab for testing can be prioritized in the order of importance. Additionally, ASV reduces analytical costs by significantly reducing the net number of samples that must be sent to the lab for testing.

ACCOMPLISHMENTS

- Developed and tested the effectiveness of using ASV to determine the concentrations of leachable chromium, uranium, (during FY92) lead, cadmium, copper nickel, zinc, and cobalt (during FY93) on soils/sediments to identify inorganic contaminant source terms and plumes underlying Sandia National Laboratories' Chemical Waste Landfill CWL) and Mixed Waste Landfill (MWL).

- Completed laboratory development and testing.

- Completed Phase II field testing at the CWL, and delivered the Phase II report.

COLLABORATION/TECHNOLOGY TRANSFER

Participation in a commercialization workshop with a private industry partner is planned for 1994.

Collaboration is with the:

New Mexico State University
Dept. of Chemistry
Las Cruces, NM 88003
Contact: Joseph Wang
Phone: (505) 646-2140

For further information, please contact:

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(509) 376-4114

Steven Slate
Technical Program Manager
Pacific Northwest Laboratories
(509) 375-3903

1.9 X-RAY FLUORESCENCE SPECTROSCOPY FOR HEAVY METALS

TASK DESCRIPTION

Downhole X-ray fluorescence (XRF) is a method for detecting and quantifying inorganic (i.e., metal) contaminant concentrations in soils above the water table using a photoelectric process. The X-ray Fluorescence instrument is a downhole probe consisting of an X-ray source and a photon detector (see Figure 1.9). The instrument probe is placed in a lined borehole. The surrounding soil and the detector are then irradiated with the source X-rays for a specified period of time.

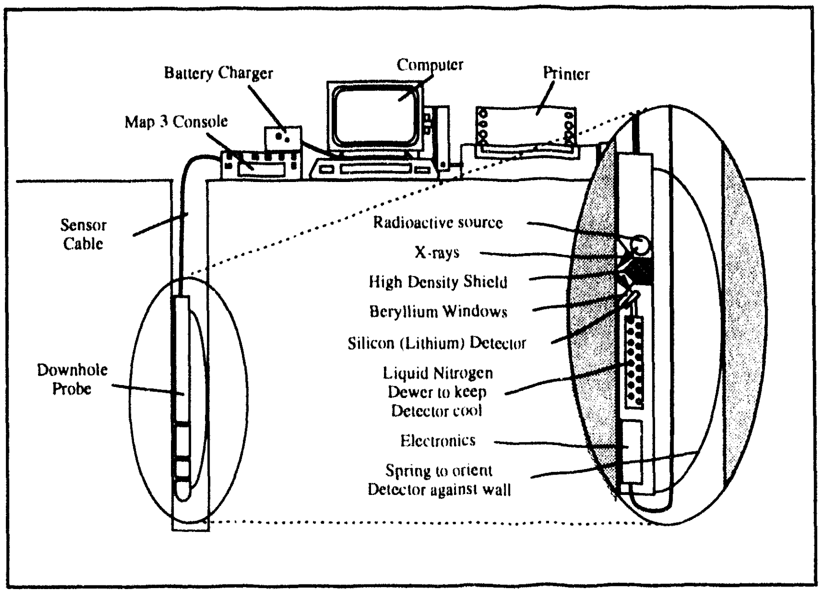

Figure 1.9. Scitec X-ray Fluorescence System.

The detector receives a combination of Compton backscatter photons as well as fluorescence photons emitted by certain atoms in the soil. Real-time assays of soil constituents can be performed when the instrument system is properly calibrated. The system also includes an analog-to-digital converter, a multichannel analyzer, and a computer processor.

Calibration of the instrument for a particular element and observation of the number of counts appearing in specific fluorescence range of the energy spectra results in a quantitative determination of the concentration of the element in the soil.

Fluorescence occurs when the source X-ray energy is greater than the electron binding energy of the K or L shell in the target atom. The source photon collides with the target atom and causes an electron vacancy in the K shell. This vacancy is filled by a transition of an L electron into the K shell and the emission of either $K\alpha$ X-ray photon and/or Auger electron. The competition between the processes is described by the fluorescence yield. The probability that a $K\alpha$ X-ray will be emitted approximates unity in high atomic number (Z) elements and approaches zero in low-Z elements. Typically, XRF is useful for elements with $Z>20$.

TECHNOLOGY NEEDS

Current technology for determination of heavy metals in soils requires sample retrieval, laboratory preparation of the sample, and data evaluation. In-situ XRF can provide a quantitative indication of heavy metal content with minimal sample preparation and data evaluation. It can be used for site investigations, post-closure monitoring, etc.

ACCOMPLISHMENTS

- Constructed a downhole cryogenic XRF probe complete with on-board signal processing electronics.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with:

Scitek
2000 Logston
Richland, WA 99352
Contact: Bill Boyce
Phone: (509) 375-5000

For further information, please contact:

Chester Shepard
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Steven Slate
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Pacific Northwest Laboratory
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1.10 NEUTRON ACTIVATION LOGGING SYSTEM

TASK DESCRIPTION

The goal of this task is to demonstrate, test, and evaluate a neutron activation logging system for in-situ measurement of contaminant metals.

The system may provide information that can be used to directly estimate waste volumes, and to support or refute evidence of waste migration. This system potentially applies to both chemical and radioactive elements.

The logging system is self-contained and operates as a stand-alone. During field operations, the probe is lowered into a borehole and data is collected. This data is stored digitally, processed rudimentarily, and displayed to allow quality assurance and initial interpretation. At a later time, the data is processed in detail and interpreted.

To generate Multi-Element (ME) data, the instrument generates a short burst of neutrons using a linear accelerator in a sealed tube within the probe. Neutrons penetrate the soil and rock surrounding the borehole, which generates gamma rays from inelastic scattering, prompt capture, and delayed capture. These gamma rays are detected by a 10% efficient, high-purity, cryogenically-cooled germanium detector. The gamma ray spectrum can be gated to distinguish signatures from different elements in the material surrounding the borehole.

TECHNOLOGY NEEDS

An advantage to ME technology is that it can analyze a 1000-times larger volume of material than an individual sample. Furthermore, it can produce in-situ assay data in a fraction of the time that it takes to submit all of the samples from a borehole to an analytical laboratory and obtain results. With the ME system, a single gamma ray spectrum can be collected in a few minutes and results are available soon after. Logging, of course, provides the opportunity to repeat measurements in the same borehole year after year for monitoring purposes.

ACCOMPLISHMENTS

In FY93, this project was completed following a demonstration at the Sandia CWL in an area of chromium contamination. The system performed as predicted and chromium was not present at concentrations above the detection threshold for the system, on the order of 1000 parts per million by weight. Numerical computations were completed to confirm performance of the system for this one case. Detection thresholds for other elements are now being determined through work sponsored by the Characterization, Monitoring, and Sensor Technology Integrated Program (CMST-IP).

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1.11 CROSS BOREHOLE ELECTROMAGNETIC IMAGING

TASK DESCRIPTION

Electrical properties such as resistivity, determined by electromagnetic methods, are unique among geophysical measurements, since the electrical property is directly related to chemical composition of the fluid passing through the geologic medium.

Fiber optic cables lower the tool, which is 2 in diameter and 6-12 in length, into boreholes to determine properties, such as the permeability, saturation, and water chemistry. Based on the attenuation and phase shift of radio frequency signals propagated between boreholes, mapping of electrical conductivity or permittivity between boreholes can be accomplished (see Figure 1.11).

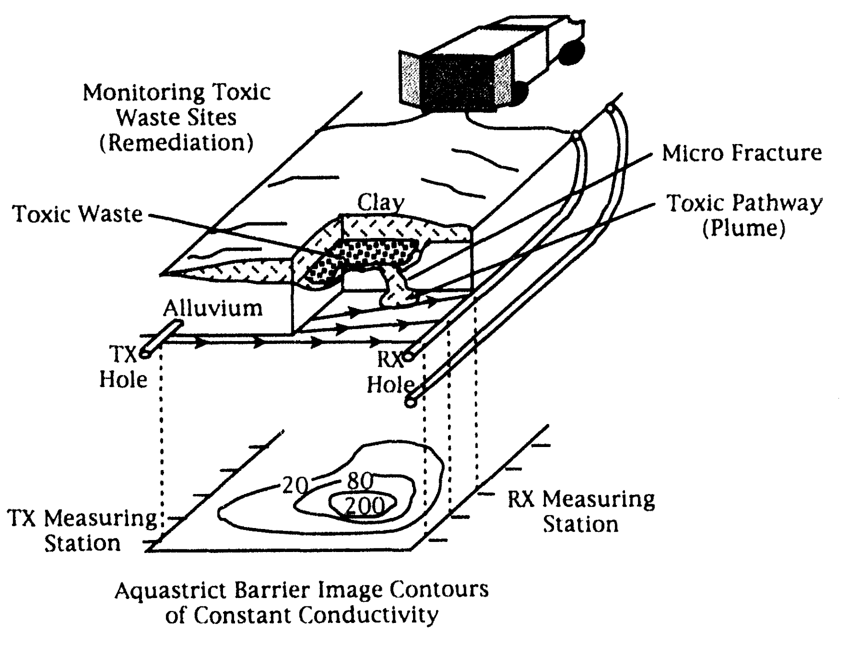

Figure 1.11 Cross Borehole Electromagnetic Imaging.

TECHNOLOGY NEEDS

In landfills containing metallic waste forms, the contrasts in electrical properties enhance the effectiveness of several electrical and electromagnetic methods. For the problem of source and plume detection at these landfill sites, the continuous wave and pulsed radar systems provide a means to image the subsurface for targets that may be uniquely suited for the method.

ACCOMPLISHMENTS

- Rocky Flats has requested that RIMtech, Inc. design a trial radio imaging survey of selected sites.
- Presented and published a paper on radio imaging of the unlined chromic acid pits at the 1993 Symposium on the Application of Geophysics to Engineering and Environmental Problems, San Diego, April 1993.
- Presented a paper on electromagnetic imaging of mixed waste landfills to

Environmental Geology Section, Geological Society of America Annual Meeting, Boston, October, 1993.

- Completed three-dimensional surveys of the 60's pits at the Sandia Chemical Waste Landfill. This survey utilized the two slant drill holes with the transmitter in the borehole and the receiver roving on the surface. These surveys delineated the covered trenches and possible plumes associated with them.

- Completed borehole-to-borehole images using the three UNCAP boreholes. These images delineated the major soil units that influence contaminant transport under the pit. The images also detected high-concentration portions of the plume beneath the pit. Reproduced the surveys a year later in 1993 with data agreement within 5%.

- Completed borehole-to-borehole images utilizing the pulsed radar system in use for treaty verification work. This survey was completed in October 1993, and correlates to the radio frequency-based images from the same boreholes.

COLLABORATION/TECHNOLOGY TRANSFER

The commercialization plan for this technology has been developed and will be utilized in 1994. The technology will be commercially available in late 1994.

Collaboration is with:

Stolar Inc.
1030 Clayton Road
P.O. Box 428
Raton, NM 87740
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For further information, please contact:

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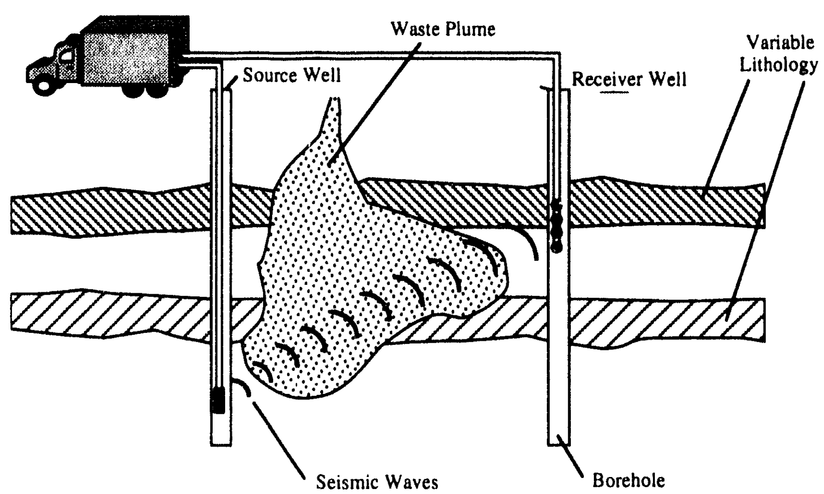
Sandia National Laboratories
(505) 845-7015

1.12 CHARACTERIZATION BY CROSSHOLE SEISMIC IMAGING

TASK DESCRIPTION

The objective of this task is to determine the applicability of high-frequency seismic crosshole imaging for characterizing contaminated subsurface sites. The technology utilizes seismic sources (high-frequency piezoelectric) and receivers (accelerometers) clamped to the borehole walls. A high-voltage signal energizes the piezoelectric crystal and causes an acoustic signal to be transmitted through the earth, where it is picked up by the receiver. The time of flight of the signal and amplitude of the signal are measured, as well as the details of the effect and the propagation path. These signals are then processed for information on the mechanical properties of the earth.



Crosshole Seismic Characterization for Defining Fluid Pathways

Figure 1.12. Seismic Imaging.

A primary goal is to demonstrate the frequency range, resolution, and sensitivity of borehole seismic methods in boreholes that cannot be filled with water (arid sites), or in which conventional clamping devices cannot be used for coupling the seismic sources and receivers to the borehole walls (see Figure 1.12). An equally important goal is to demonstrate that high-resolution seismic imaging can be used to characterize structure and lithology related to transport properties in a routine and cost-effective manner.

The scope of this project is to start with existing technology that uses piezoelectric transducers for transmitting and receiving high-frequency seismic energy in water-filled boreholes, and adapting this technology to boreholes which are often only partially filled with water or completely dry. In addition, boreholes in contaminated sites are generally lined with a relatively fragile material, so conventional clamping devices cannot be used.

The approach is staged to first evaluate different mechanisms for borehole coupling, which will affect frequency content and amplitude of the seismic signals. If successful, the sources and clamping mechanisms will be improved to allow shear wave transmission in addition to compressional wave transmission. An equally important task is to demonstrate in-field data collection and imaging methods, such that the imaging results can be obtained in an efficient and cost-effective fashion. The latter phases of the project will use this technology at an arid site that will be remediated. The last phase will be to transfer as much technology as possible to private industry through Science and Engineering Associates, Incorporated.

TECHNOLOGY NEEDS

Seismic imaging has proven effective and useful in oil and gas exploration and reservoir characterization. Seismic techniques are the established method for mapping the structural geology of sites deep within the earth. Recent technological advances have made it possible to identify fluid-saturated regions. This advanced technology, appropriately applied, is very suitable for identifying, locating, and characterizing hazardous waste sources, waste plumes, and local geologic structure and hydrology. Seismic methods are also capable of penetrating up to tens of feet with resolutions of less than three feet, compared to standard geophysical approaches using electrical or electromagnetic approaches which can not resolve targets less than 10 feet or depths greater than 15 feet.

ACCOMPLISHMENTS

Successfully demonstrated the seismic crosshole system at the UNCAP holes in October. Kilohertz seismic energy was used to image the area between UNCAP 3 and UNCAP 2. The coupling mechanism performed as designed.

COLLABORATION/TECHNOLOGY TRANSFER

The project involves collaboration with:

Science & Engineering Associates
1570 Pacheco, Suite D-1
Santa Fe, NM 87501
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Phone: (505) 983-6698

For further information, please contact:

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Richard Scott
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Lawrence Berkeley Laboratory
(510) 273-7878

1.13 MAGNETOMETER TOWED ARRAY

TASK DESCRIPTION

The magnetometer towed array, also called Surface Towed Ordnance Locator System (STOLS™) was built by the U.S. Navy as a proof-of-principal, nonintrusive characterization system to locate and identify buried ordnance (see Figure 1.13). Sandia, in conjunction with the U.S. Navy and Geo-Centers, Inc., is furthering the magnetometer towed array system to meet the DOE need for rapid and noninvasive detection and quantification of subsurface waste forms.

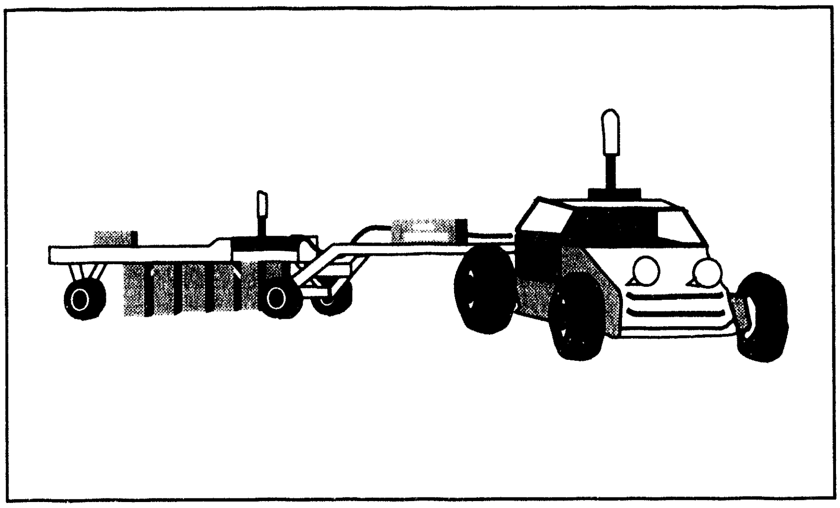

Figure 1.13. Magnetometer.

Current technology is based on walkover magnetometer surveys which provide low resolution data at the rate of an acre or two per day. STOLS™ has been commercialized by the Geo-Centers Inc. This vehicle-based system deploys a non-intrusive sensor platform containing seven total-field magnetometers with precise satellite positioning for locating the magnetic data. The acquired data sets are processed to produce high resolution magnetic maps of the surveyed area (on the order of 0.5-meter resolution).

The vehicle that tows the sensor platform is rugged, for handling the terrain variations in diverse field conditions. It enables the system to rapidly cover the survey area at a rate of at least fifteen acres per day. The vehicle has been designed to exhibit a low magnetic signature in order to minimize interference with the magnetometers. In addition, the sensor platform, itself composed of low-magnetic materials, has been designed to keep the sensors at a sufficient distance from any spurious magnetic sources. An on-board computer accepts directional information from an electronic compass, and position coordinate information is now updated once per second by the dynamic global positioning system. The on-board computer also provides real-time information to the driver.

The sensor platform contains the array of seven cesium-vapor magnetometers spaced at 0.5 meter intervals perpendicular to the direction of travel. Each of these magnetometers measure the total field strength at a rate of twenty points per second. This rate yields a total data-point density of 100,000 data points per acre.

The field strength at any point is determined by the sum of the Earth's field plus any local variations caused by the presence of ferrous materials. Data from a nearby reference station is used to remove the effects of the Earth's field from the sensor platform data. This step leaves behind only the variations due to local ferrous objects.

Precise positioning data is acquired simultaneously with the magnetic data. Based on a global positioning system, the location of the sensors is calculated at every instant to provide positions for every magnetic data point. After interpolating the positioned magnetic data to a regularly-spaced grid, magnetic maps of the survey area are readily produced and are repeatable from survey-to-survey. On these maps, the magnetic variations due to local ferrous objects are readily located through the use of appropriate color scales. In addition, areas that the system has yet to survey are clearly seen, and can be subsequently located and surveyed. Local landmarks and locations significant to a given survey can also be indicated.

Displayed on a video monitor, the magnetic map of a surveyed area provides the user interface to the STOLS™ semi-automated target analysis for small isolated targets. Using a mouse, the user selects an anomaly due to a given ferrous target. The target analysis then performs an iterative least-squares model matching to determine the best fit of magnetic moment and depth to the selected anomaly for small isolated targets. Detection ranges include small pieces of ordnance (containing a few pounds of iron) down to a maximum depth of 6.5 meters.

TECHNOLOGY NEEDS

The STOLS™ technology represents a capability to perform environmental cleanup competently and efficiently. With rapid and repeatable surveying capability, coverage of broad survey areas can be performed in a cost-efficient manner that can be reliably documented. Additionally, target analysis can begin the remediation procedure by providing estimates of the location and quantities on the subsurface targets, and providing needed guidance for the total environmental clean-up procedure.

ACCOMPLISHMENTS

- To aid in the evaluation and selection of a dynamic Geographic Positioning system (GPS), a navigation system test track was setup at the NRL Chesapeake Beach Detachment, Chesapeake Beach, MD. Field evaluations began the week of February 1, 1993.

- Eight vendors of locator systems demonstrated their ability to locate targets on the test track while driving through the test track at 5 MPH. Some vendors demonstrated real-time 100% accuracy at Û meter error, and 100% accuracy at Û 0.5 M error in post processing. Other vendors were less than 10% accurate. A report documenting the performance of the eight navigation systems and the test setup was written and distributed.

- Based on the field test results, a GPS system was selected and purchased for incorporation into the towed array. The $100K Trimble Navigation 4000 SSE dynamic GPS system was purchased with both MWLID and Navy funds.

- Two trial surveys were conducted at the RB-11 landfill to make sure the actual field demonstration would be successful. In April, a trial survey was conducted with hand-held magnetometers, and in May, a trial survey was conducted using dynamic GPS navigation systems.

- During the week of September 7, 1993, the Magnetometer Towed Array was successfully demonstrated at the RB-11 landfill. Less than two hours were required to survey the test site.

COLLABORATION/TECHNOLOGY TRANSFER

This technology will be offered commercially in late 1994 and involves collaboration with the following commercial industries:

U.S. Naval Research Laboratory
560 Center Drive
Port Hueneme, CA 93043-4328

GeoCenters, Inc.
7 Walls Avenue
Newton Center, MA 02159

For further information, please contact:

John Cochran
Principal Investigator
Sandia National Laboratories
(505) 848-0415

George Allen
Technical Program Manager
Sandia National Laboratories
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1.14 POST-CLOSURE MONITORING

TASK DESCRIPTION

The objective of this task is to design, construct, install, field test, and evaluate an automated state-of-the-art soil moisture monitoring system for measuring the hydrologic performance of migration barriers and advanced surface covers for remediating landfills. The test will involve a comparison of automated state-of-the-art Time Domain Reflectometry (TDR) technology with the conventional neutron moisture gage. Three brands of TDR will be evaluated, including one manufactured in Germany, one by Campbell Scientific, and one manufactured in Logan, Utah. Performance, reliability, and cost of each of the technologies will be compared and documented. Radiation, volatile organic compounds, or other chemical detectors may also be evaluated as possible components of an integrated monitoring system.

ACCOMPLISHMENTS

Prepared draft evaluation of one brand of time domain reflectometry soil moisture system.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with the following commercial industries:

University of Houston
Dept. of Chemical Engineering
4800 Calhoun
Houston, TX 77204
Contact: Frank Kovarik
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Dupont Chemical Laboratory
Jackson Laboratory
Deep Water, NJ 08023
Contact: Mark Noll
Phone: (609) 540-3654

University of New Mexico
Dept. of Civil Engineering
Wagner Hall, Rm. 118
Albuquerque, NM 87131
Contact: Bruce Thomson
Phone: (505) 277-4729

For further information, please contact:

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Los Alamos National Laboratories
(505) 667-8483

Bruce Erdal
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Los Alamos National Laboratories
(505) 667-5338

1.15 IN SITU DETERMINATION OF RADIONUCLIDE CONTAMINANTS

TASK DESCRIPTION

The objective of this technology is to provide a three-dimensional quantitative concentration profile for each radionuclide present in the matrix, by making non-intrusive, non-destructive, passive, in-situ measurements from the surface and from boreholes and wells penetrating the matrix.

Two types of instrumentation are used: one for making measurements above the surface of the ground (or from outside a contained medium), and the other for making measurements from wells or boreholes penetrating the medium. Both types of instrumentation consist of high resolution germanium diode gamma-ray spectrometers which collect a gamma energy spectrum from the environment and provide isotope-specific radionuclide concentration data.

TECHNOLOGY NEEDS

In-situ analyses are faster, better, cheaper, and safer. Results are available in minutes instead of months. Concentration data is obtained for sample sizes on the order of a ton instead of a gram; this provides a more representative sample and reduces sampling errors. Analytical costs are tens of dollars per sample instead of thousands. The potential for spread of contamination, waste disposal, and personnel exposure is virtually eliminated.

ACCOMPLISHMENTS

Modifications were completed to the downwell germanium spectrometer, which will allow it to pass through directional wells having a smaller radius of curvature than could be transited with the original equipment. Delays encountered in the installation of the daylight wells under the RB-11 pits at Kirtland Air Force Base caused slippage of the demonstration to November, 1993.

For further information, please contact:

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Extraction/Transformation Technologies

Section 2.0

2.1 THERMAL ENHANCED VAPOR EXTRACTION SYSTEM

TASK DESCRIPTION

The objective of this technology is to demonstrate the combination of two soil heating methods (resistive and dielectric) with a vacuum vapor extraction system. The added heat will increase the mass removal rate of the soil contamination (see Figure 2.1).

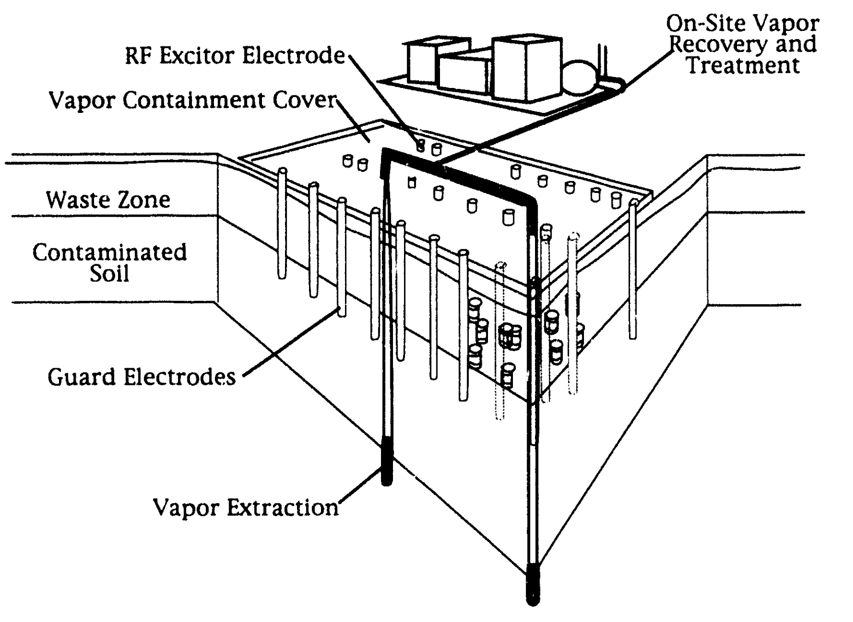

Figure 2.1. Thermal Enhanced Vapor Extraction System.

Three rows of electrodes are placed through an organic waste disposal cell (tri-plate array configuration) down to a depth of 25 feet. The center row electrodes are connected as the excitor (energy input) source and the two exterior rows are used as ground/guard electrodes to help contain the input energy to the treatment zone. Surface hardware connecting the electrodes are then installed. Two dual-purpose vacuum vapor extraction wells/electrodes are installed as part of the excitor array. A vacuum blower and off-gas treatment system is provided for the removal of the heated soil contaminants.

Resistive heating technology passes powerline frequency (60 Hz) through the soil using the conductive path of the residual soil water. Powerline frequency energy input is controlled through a multi-tap transformer to allow for the changing impedance of the soil as soil water is removed. Voltages begin at ~200V and can be increased in steps up to 1600V. Water addition to the excitor electrodes is necessary to moderate the increased soil resistance caused by removal of the soil water. The soil heating technology vaporizes the added water into steam and also provides another mechanism for enhancing contaminant removal. When the temperature nears 100°C, the resistive heating energy input becomes constrained by the increased soil resistance (lack of residual soil water as a current conducting path). At this point, it is not effective to continue with the resistive heating mode, and switching to the radiofrequency heating is indicated.

Radiofrequency (RF) heating uses high-frequency microwaves (2-20 MHz) to heat the soil by a mechanism known as dielectric heating. The RF energy is transmitted through the soils without using residual soil water as the conductive path. Energy deposition is a function of the frequency applied and the dielectric features of the soil medium. Frequency selection is based on tradeoffs of wave penetration depth (lower frequencies penetrate further) and the dielectric constant of the soil profile. Typical frequencies used are around 6.78 MHz. The energy output from the radiofrequency transmitter is passed through a network of capacitors to match the impedance of the soil in the treatment zone to the output of the power transmitter. This hardware is necessary to minimize energy reflected from the soil and maximize the energy absorbed by the soil. By adjustment of the transmitter frequency and matching network, soil heating can continue up to 250°C or greater.

TECHNOLOGY NEEDS

Landfill disposal pits used for the disposal of a wide spectrum of organic chemicals are difficult to remediate by vacuum vapor extraction technology due to low mass removal rates. Innovative technologies that increase the mass removal rates of in-situ extraction technologies are needed to reduce the cost of in-situ remediation of difficult, high-boiling organic waste mixtures.

ACCOMPLISHMENTS

- Site characterization completed to collect soil contaminant information for engineering design efforts.

- Engineering design efforts began with a laboratory column treatability study of actual soil removed during site characterization. This effort concluded that a treatment design temperature of 200°C is needed. Air permeability tests were performed and identified a very highly permeable soil that is beneficial to the subsurface containment of vapor and steam expansion caused by soil heating. Subsurface containment modeling has shown that only a moderate soil vacuum is necessary to contain the thermodynamic gas expansion. A soil heating (electrical and RF) and subsurface instrumentation design report was completed which supported the submittal of a Resource Conservation and Recovery Act (RCRA) RD&D permit application to the New Mexico Environment Department.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with the following commercial industries:

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Containment/Stabilization Technologies

Section 3.0

3.1 CONTAINMENT AND STABILIZATION OF BURIED WASTE

TASK DESCRIPTION

This technology aims to develop, demonstrate, and implement advanced grouting materials for in-situ stabilization of contaminated soils and the placement of impermeable, highly durable subsurface barriers. The developmental effort focuses on cementitious and soil cement mixtures compatible with commercially available placement techniques.

TECHNOLOGY NEEDS

Geotechnical engineering and well drilling and completion technologies provide placement techniques for the grouting of fractured media surrounding waste disposal sites and for the in-situ stabilization of waste contaminated soils. Unfortunately, commercially available materials for these applications generally do not meet the requirements for waste site remediation.

ACCOMPLISHMENTS

Formulations for use in an arid environment were optimized and characterized. The major placement techniques considered were jet grouting, soil mixing, and soil sawing. Cementitious grouts with permeabilities of the order of 10^{-10} to 10^{-11} cm/s suitable for monolithic grout subsurface barriers were developed. Permeability after accelerated leaching and repeated wet-dry cycles was of the order of 10^{-10} to 10^{-9} cm/s. The results compare favorably with the EPA permeability limit of 10^{-7} cm/s for landfills.

The developed superplasticized grouts and soil cements have significantly superior mechanical, physical and durability properties than those of conventional formulations. The permeabilities are two to five orders of magnitude less than for other materials frequently used as caps and barriers such as clay, soil-bentonite and cement bentonite slurries. Therefore, the dimensions of the barriers can be reduced significantly.

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3.2 MIGRATION BARRIER COVERS FOR MIXED WASTE LANDFILLS

TASK DESCRIPTION

The objective of this project is to provide field-tested capping alternatives, including the EPA RCRA cap, and calibrated water balance models that can be used in the assessment phase of the Remedial Investigation and as a component of the Corrective Measures Study for selecting remediation alternatives for the MWLID. The goal is to ensure that cost-effective capping technologies are available so that cap design can be selected based on the level of hydrologic control needed at the site.

Over the past eight years, parallel and collaborative research and development by LANL, PNL, Idaho National Engineering Laboratory (INEL), USDA-ARS, USGS, and the UMTRA program has explored several alternative long-term migration barrier cover technologies for interim stabilization and final closure of radioactive waste landfills in arid sites (see Figure 3.2).

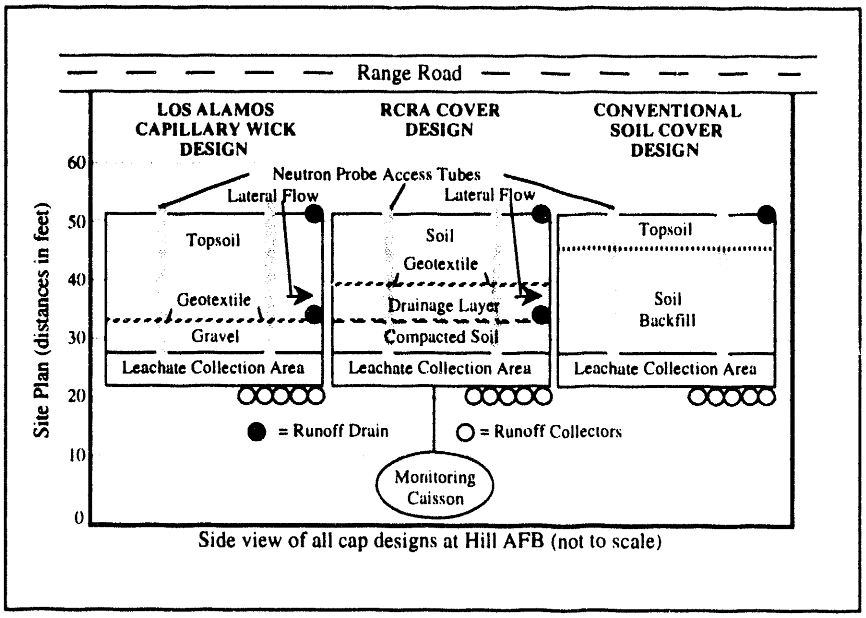

Figure 3.2. Migration Barrier Cover Systems.

These barrier technologies have addressed means to control erosion, deep percolation, and biological intrusion using engineered covers constructed of synthetic and/or natural geologic materials. A systems approach has been taken in some of this work, such that the underlying hydrological and biological phenomena was used to design barriers that control the fate of precipitation falling on the site. The spectrum of designs vary from simple soil barriers that have optimum configurations of soil, plant cover, and surface slope, to more complex multi-layered cover profiles incorporating engineered barriers that inhibit downward movement of soil moisture. The EPA's RCRA cap uses compacted clay as a hydraulic barrier, while others employ a capillary barrier to divert water laterally. Unfortunately, few of those designs, including EPA's RCRA cap, have been constructed in the field and monitored in a way that allows a complete evaluation of performance characteristics. Those few that have been field-tested have been evaluated under very specific climatic and environmental conditions.

LANL has conducted the basic research and begun to field test various landfill cover designs, and has had some success in reducing erosion and percolation of water into underlying waste under local climatic conditions. However, tests for some of these barrier concepts in other climatic conditions (i.e. at Hill Air Force Base in Utah) and for wastes other than radionuclides have just begun. Factors such as climate, soils, vegetation, and waste composition are important site attributes that affect both the design and the performance of migration barrier cover systems. Field testing will evaluate the performance levels of each cap in preventing water percolation into the waste and in preventing soil erosion.

TECHNOLOGY NEEDS

Field-tested migration barrier cover designs, tailored to the climate, can serve as the sole containment technology or as a component of an integrated barrier system that incorporates other barrier concepts, along with cover, to contain wastes. In addition, the hydrologic control exerted by the cover can be used to establish optimum moisture conditions in the waste backfill to improve performance of other treatment technologies such as in-situ vitrification (ISV), vapor extraction, and other in-situ treatment technologies. Relative to the excavate and re-bury option, containment with field-tested migration barrier designs can reduce remediation costs 10-1000 times and still ensure regulatory compliance.

ACCOMPLISHMENTS

- Selected and delivered a report on the best barrier design based on performance data, from a demonstration at Hill Air Force Base.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with the following commercial industries:

USDA-ARS

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3.3 DECISION SUPPORT SYSTEM TO SELECT LANDFILL COVER SYSTEM

TASK DESCRIPTION

The objective of this technology is to provide risk managers with a defensible, objective way to select capping alternatives for remediating radioactive and mixed waste landfills. The objective will be achieved through a joint project between LANL and USDA-ARS by developing a multi-objective decision-making software system (DSS), with embedded simulation models, to design and evaluate engineered surface barriers for mixed waste landfills. The data collected from the Migration Barrier Covers for Mixed Waste Landfills project will be used to evaluate the DSS. The task includes testing the prototype DSS for remediation of waste disposal sites with migration barrier cover technology, using the designs and database from the existing cover barrier field demonstration at Hill Air Force Base in Utah. The objectives of the work include:

- Assembling the technical database to develop site-specific parameters for the knowledge-based system (KBS);
- Incorporating the multi-objective analysis tools into the existing DSS;
- Assembling the heuristic database and scoring functions for the DSS;
- Evaluating the DSS with monitoring data from Hill AFB, and selecting the best barrier cover design for meeting the regulatory requirements at a minimum cost;
- Using the DSS to design and evaluate migration barrier cover alternatives for mixed waste landfills; and
- Comparing DSS predicted performance with monitoring data from the planned MWLID barrier technology demonstrations at Hanford and SNL.

Applications of a DSS to natural resource management and to landfill cover remediation have been explored, and a prototype DSS has been partially developed by the USDA-Agricultural Research Service for water quality management. The DSS uses a computer model (a new version of the EPA's HELP model) to calculate water balance. The technical criteria include runoff erosion, percolation, interflow, and evapotranspiration, given the climate of the area. Other criteria are pertinent regulations and cost. All criteria go towards an overall score used to determine which cap is best for the site.

A PC-based prototype DSS software package, running with Windows 3.1, is under development. It will be a user-friendly coupling between symbolic processing and numerical near-surface hydrologic modelling. The embedded KBS will integrate confidence limits and exceedence probabilities from stochastic conjectural analyses of hydrologic variables in space and time, and the symbolic objects that influence landfill technology. The integration will result in a DSS that should improve long-range predictability of migration barrier performance, by incorporating complex environmental processes, along with the management issues, into the decision-making process.

Interpreting the output of the KBS applied to landfill design and remediation problems, particularly when multiple and sometimes conflicting objectives exist, requires the aid of decision analysis tools to simplify the decision-making process. For example, the hydrologic analysis from the KBS might identify a particular barrier design as "better" in controlling runoff (and erosion) from the site, but at the expense of increasing water infiltration into the landfill. A method to decide whether the increased infiltration will significantly enhance the potential of deep percolation and concomitant migration of solutes toward groundwater, and whether this enhanced migration has relevance in light of other factors, such as thickness of the unsaturated zone, potential use of the water, climate, etc. can be very useful.

The DSS will use dimensionless scoring or utility functions parameterized from the quantitative KBS output and expert judgment to convert the range of the decision variables to a unitless common range. This process allows one to combine the decision variables and rank the alternative designs. A major task of this project is to integrate a new decision-making methodology into the existing DSS in order to eliminate much of the subjectivity in existing multi-objective methods.

TECHNOLOGY NEEDS

Containment technologies, including surface caps, are essential to reduce the potential for contaminant migration from the landfill by an alteration of the surface and/or subsurface soils. The process of selecting containment cover technologies for landfills requires consideration of many complex and interrelated technical, regulatory, and economic issues. A decision support system is needed to integrate the knowledge of experts from scientific, engineering, and management disciplines to help in selecting the "best" capping practice.

ACCOMPLISHMENTS

Developed a prototype decision support system and delivered a report on barrier cover demonstrations to evaluate alternatives using a Knowledge-Based System.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with the following National Laboratories and commercial industries:

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3.4 SUBSURFACE BARRIER EMPLACEMENT DEVELOPMENT

TASK DESCRIPTION

Subsurface barrier emplacement involves putting an impermeable barrier (composed of some kind of grouting material) in below a landfill (see Figure 3.4). It has to be emplaced without disturbing the landfill. There are two emplacement methods that are being tested. The first is permeation grouting, which uses a slight pressure to inject the grout and takes advantage of the natural porosity of the soil by letting it flow into the soil. The second is jet grouting by mixing, which takes a drill and rotates while injecting the grout. This intentionally fractures the soil and intermixes it with the grout. For both, the boreholes will be drilled approximately two to three meters apart.

Initially, feasibility of each technique will be evaluated, followed by evaluation of design parameters such as borehole separation, depth and arc limitations, etc.

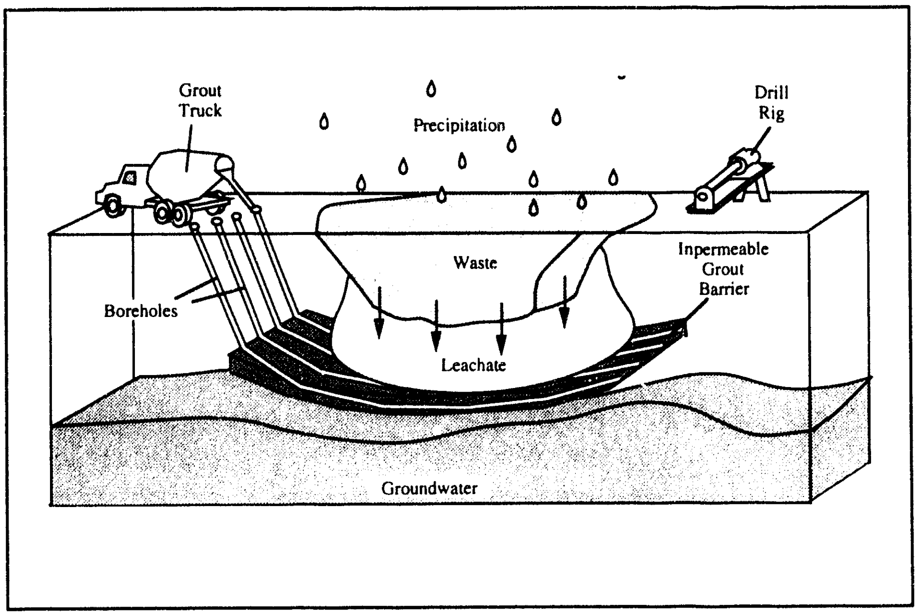

Figure 3.4. Subsurface Barrier Application.

TECHNOLOGY NEEDS

The current state-of-the-art for emplacement of subsurface barriers in near surface soils lies primarily with vertically emplaced barriers. Subsurface horizontal to sub-horizontal barriers that retard vertical mass movement are not currently employed in the civil engineering applications.

ACCOMPLISHMENTS

- Completed report/literature review summarizing the technological aspects of all system components required for demonstrating a subsurface barrier emplacement.

- Completed field-scale permeation grouting experiment. Field testing consisted of grouting in vertical and horizontal boreholes using four different barrier materials. The barrier materials used were two ultrafine cements, a mineral wax/bentonite mixture, and a sodium silicate grout. Numerous non-intrusive geophysical techniques were used to identify where the grout flowed. Geophysical techniques used included: cross hole seismictomography, grout penetrating radar, electromagnetic induction, neutron probe and downhole temperature logs. Finally the cementitious grout site was excavated exposing the grout. Observations shall be compared with the crosshole tomography data when the analysis is complete.

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3.5 DRY BARRIER APPLICATIONS FOR LANDFILLS

TASK DESCRIPTION

The objective of this project is to develop and demonstrate an air-enhanced dry barrier for application to landfills in arid environments (see Figure 3.5). This technology is based on the well-founded capillary barrier concept: the contrast in unsaturated hydraulic conductivity of a coarse layer (barrier) and an overlying finer layer that limits downward water flow. This technology goes beyond the conventional capillary barrier in that the coarse layer is dried with lateral air flow through the layer, preventing moisture accumulation in the layer and ensuring that its unsaturated hydraulic conductivity remains low. The drying of the barrier by air can be accomplished by passive or active means, in order to assure that the air flow is sufficient to load and transport any net recharge to the atmosphere. The dry barrier may also have application as a method for stripping gas-phase contaminants.

The air-enhanced dry barrier could assume numerous forms and functions. Most simply, it can be a component of a cap or cover system. The barrier would principally be used to limit vertical infiltration through the cap. Another application would be in engineered liner systems. The air-dried layer can be used as a final barrier to prevent leachate movement beyond the landfill, and to strip denser-than-air gas-phase constituents (e.g., TCE) as they migrate downward. This application does not rely on an engineered liner, but rather utilizes the existing heterogeneous soil beneath most landfill sites. Air flow through a highly air-permeable layer beneath the landfill can be induced with vertical or directional holes to supply and remove air. These schemes may be able to utilize the prevailing westerly winds to induce sufficient air flow through the layer without relying on blowers or vacuum pumps. For applications underneath landfills, the contaminant concentration of the air is likely to be low enough so as not to require treatment.

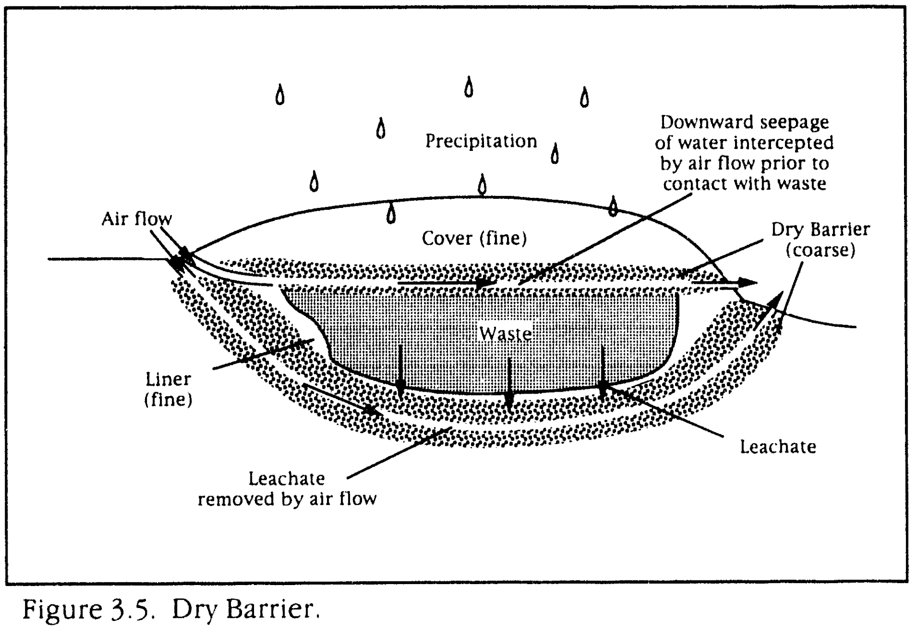

Figure 3.5. Dry Barrier.

This project will evaluate the feasibility of the dry barrier concept for applications at landfills in arid environments by a combination of laboratory, design and field efforts. First, a better understanding of unsaturated transport properties of both engineered and natural soils is needed to develop the dry barrier concept. A novel technique will be evaluated as a means of simultaneously obtaining gas permeability and unsaturated hydraulic conductivity. Small-scale testing of the dry barrier concept will utilize sandbox experiments as two-dimensional models of dry barriers. These experiments will evaluate the ability of lateral air flow to remove downward flowing water using soil types with various properties. Based on the laboratory studies, dry barriers for field demonstration will be designed. At this point, the feasibility of different applications of dry barriers will be assessed. This project will culminate with field demonstration of the dry-barrier concept at a local site.

TECHNOLOGY NEEDS

Most landfills require both above-ground and below-ground barriers. In arid environments, capillary barriers are often used in containment systems. Incorporating dry barriers into the containment systems would allow inexpensive isolation in many circumstances, and extend the probable life of the capillary barrier. The dry barrier concept addresses a number of issues associated with landfills. If a low-maintenance dry barrier can be incorporated into the design, the cover design can be improved, and perhaps its longevity can be extended. Dry barriers used as liner can serve as both a redundant barrier to liquid flow and as a means of stripping gas-phase contaminants. For existing landfills on alluvial deposits, it may be possible to use an existing coarse layer as a dry barrier.

ACCOMPLISHMENTS

- Demonstrated feasibility of the dry barrier concept in bench-top tests.
- Measured site-specific soil properties required for dry barrier design.
- Conducted numerical and analytical study of dry barrier performance.
- Completed an engineering assessment of an active dry barrier for Albuquerque, Los Alamos, and Salt Lake City.
- Conducted active and passive field measurements of dry barrier performance.

COLLABORATION/TECHNOLOGY TRANSFER

This project involves collaboration with the following commercial industries:

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How To Get Involved

Section 4.0

4.0 HOW TO GET INVOLVED

WORKING WITH THE DOE OFFICE OF ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT

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

Cooperative Research and Development Agreements (CRADAs)

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

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

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

Procurement Mechanisms

DOE EM has developed an environmental management technology development acquisition policy and strategy that uses phased procurements to span the RDDT&E continuum from applied R&D concept feasibility through full-scale remediation. DOE EM phased procurements make provisions for unsolicited proposals, but formal solicitations are the preferred responses. The principle contractual mechanisms used by EM for industrial and academic response include Research Opportunity Announcements (ROAs) and Program R&D Announcements (PRDAs). EM uses the ROA to solicit advanced research and technologies for a broad range of cleanup needs. The ROA supports applied research ranging from concept feasibility through full-scale demonstration. In addition, the ROA is open continuously for a full year following the date of issue and includes a partial procurement set aside for small businesses. Typically, ROAs are published annually in the *Federal Register* and the *Commerce Business Daily*, and multiple awards are made.

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

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

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

Licensing of Technology

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

Technical Personnel Exchange Assignments

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

Consulting Arrangements

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

Reimbursable Work for Industry

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

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

EM Small Business Technology Integration Program

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

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

CONTACT

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International Technology Exchange Division
EM-523
Environmental Restoration and Waste
Management Technology Development
Washington, D.C. 20585
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EM Central Point of Contact

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

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

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

Office of Research and Technology Applications

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

For more information about these programs and services, please contact:

Claire Sink, Director
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EM-521
En ental Restoration and Waste
Management Technology Development
U.S. Department of Energy
Washington, D.C. 20585
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Acronyms

Section 5.0

5.0 ACRONYMS

ASV	absorptive stripping voltammetry
CMST-IP	Characterization, Monitoring, and Sensor Technology Integrated Program
CRADA	Cooperative Research and Development Agreement
CWL	Chemical Waste Landfill
DOE	U.S. Department of Energy
DSS	decision-making software system
DT&E	Demonstration, Testing, and Evaluation
EM	Environmental Restoration and Waste Management
GC	gas chromatograph
GCMS	gas chromatograph and mass spectrometer
GIS	geographical information system
GPR	ground-penetrating radar
ID	Integrated Demonstration
INEL	Idaho National Engineering Laboratory
IP	Integrated Program
ISV	in situ vitrification
KAFB	Kirtland Air Force Base
KBS	knowledge-based system
LANL	Los Alamos National Laboratory
LCMS	Landfill Characterization and Monitoring System
LCS	Landfill Characterization System
LLNL	Lawrence Livermore National Laboratory
ME	multi-element
MWLID	Mixed Waste Landfill Integrated Demonstration

NRL	Naval Research Laboratory
ORTA	Office of Research and Technology Applications
PNL	Pacific Northwest Laboratory
PRDA	Program Research and Development Announcement
PVC	poly-vinyl chloride
R&D	research and development
RCRA	Resource Conservation and Recovery Act
RD&D	Research, Development, and Demonstration
RDBSs	Relational Database Systems
RF	radio frequency
ROA	Research Opportunity Announcement
SB-TIP	Small Business-Technology Integration Program
SBIR	Small Business Innovation Research
SNL	Sandia National Laboratories
SP	spontaneous potential
SRS	Savannah River Site
STOLS™	Surface Towed Ordnance Locator System
TDEM	time-domain electromagnetic
TDR	time-domain reflectometry
UMTRA	Uranium Mill Tailings Remedial Action
UNCAP	Unlined Chromic Acid Pit
USDA-ARS	U.S. Department of Agriculture-Agricultural Research Service
USGS	U.S. Geological Survey
UV	ultraviolet
VOCs	volatile organic compounds
XRF	X-ray fluorescence

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