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Adaption of the Magnetometer Towed Array Geophysical System to Meet Department of Energy Needs for Hazardous Waste Site Characterization

John R. Cochran, Jim R. McDonald, Richard J. Russell,
Richard Robertson, Edward Hensel

Prepared by
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**Adaption of the
Magnetometer Towed Array Geophysical System to
Meet Department of Energy Needs for
Hazardous Waste Site Characterization**

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Abstract

This report documents U.S. Department of Energy (DOE)-funded activities that have adapted the U.S. Navy's Surface Towed Ordnance Locator System (STOLS) to meet DOE needs for a "... better, faster, safer and cheaper ..." system for characterizing inactive hazardous waste sites. These activities were undertaken by Sandia National Laboratories (Sandia), the Naval Research Laboratory, Geo-Centers Inc., New Mexico State University and others under the title of the Magnetometer Towed Array (MTA).

The MTA, as currently configured, is a vehicle-based system that measures the strength of the Earth's magnetic field while traveling at speeds of 5 to 15 miles per hour (mph). Information from satellites is used by the Trimble 4000 SSE differential global positioning system (DGPS) to provide the location of the moving system every second. Seven cesium vapor magnetometers are mounted on a ten-foot wide platform; each magnetometer takes 20 measurements per second. This rate provides about 70,000 measurements per acre (at 5 mph) or one measurement for every 1.5 square feet. The data are then automatically processed to provide high resolution maps that show the locations and magnetic

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characteristics of buried ferrous objects. As detailed in this report, data collected on such a fine grid provide a number of significant advantages over conventional data collected on a coarse grid with nodes on five- or ten-foot centers.

Efforts spanning five years are summarized. In fiscal year (FY) 1992 the original, proof-of-principle STOLS was used to characterize buried wastes at several Sandia landfills. Though successful, system weaknesses were identified.

DOE Office of Technology Development funds were used to correct those identified weaknesses. During FY 1993 a DGPS-based navigation system was integrated into the MTA. Geo-Centers Inc. independently built a commercial version of STOLS which is marketed as the Search Technologies Inc. system. In September of 1993 the system was very successfully demonstrated at an Air Force mixed waste landfill near Albuquerque, New Mexico.

Better numerical methods for analyzing MTA data from landfills were developed during FY 1994. The utility of deploying other sensors on the existing platform was explored, and two large mixed waste landfills at Los Alamos National Laboratory were surveyed in FY 1994. Due to other DOE priorities, funding was terminated in early FY 1995. Overall, the MTA program was an outstanding technical success which also demonstrated effective teaming of private industry, a university, and DOE and Department of Defense (DoD) laboratories.

Acknowledgements

The relationship between Sandia, the Naval Research Laboratory and Geo-Centers Inc. began in the summer of 1990, and New Mexico State University (NMSU) researchers joined this team in 1992. A very large number of other organizations and individuals have supported the adaption of STOLS to meet the DOE hazardous waste site characterization needs.

With efforts spanning five years, individuals deserving recognition will be inadvertently overlooked; however, the authors would like to thank the following parties.

The entire staff of Sandia's former Mixed Waste Landfill Integrated Demonstration (MWLID) Program were very supportive. Jim Phelan helped bring NMSU into the MTA project, Bob Floran paid for the burial of the calibration targets, Jennifer Nelson successfully managed the ever changing MWLID Program, Bob Helgesen helped coordinate the burial of the targets at the Chemical Waste Landfill, Grace Bujewski supported the field demonstration at RB-11 (including doughnuts), Sandra Wagner and Tom Burford help keep the project straight (even when the path wasn't clear) and Cecelia helped work public relations issues.

Special thanks go to David Betsill and Jim Swanson who both went the extra mile. Jim took ownership for the burial of the calibration targets and David provided friendship and needed in-house support. Rarilee Conway and Mike Wade of Sandia's Environmental Restoration Program have been avid supporters of innovative approaches for the assessment of Sandia's Technical Area 2. Additionally, Sandia supervisors David Gallegos and Paul Davis encouraged and supported this innovative work.

Kim (Dalton) Linder of NMSU was the force behind the MAPER software and "burned the midnight oil" to provide timely support. David Hyndman of Sunbelt Geophysics in Albuquerque provided support and sage geophysical advice. The demonstration of the MTA at Los Alamos National Laboratory occurred only with the support of Alan Cogbill and Cheryl Rofer.

At Geo-Centers, Jack Foley has been a tireless supporter of the MTA and our teaming efforts. John Mackey provided local Geo-Centers support and the Geo-Centers field crews, including Al Crandall and Fenoy Butler, kept the system going through sun and mud.

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List of Acronyms

DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE/OTD	DOE Office of Technology Development
ER	DOE Environmental Restoration Program
EM-40	DOE Environmental Restoration Program
EM-50	DOE Office of Technology Development
EOD	Explosive Ordnance Disposal Technology Center
FY	Fiscal Year
KAFB	Kirtland Air Force Base
LANL	Los Alamos National Laboratory
LCMS	Landfill Characterization and Monitoring System
MAPER	Multi-sensor Analysis Program for Environmental Restoration
MDA	Material Disposal Area
mph	Miles per hour
MWLID	Mixed Waste Landfill Integrated Demonstration Program, administered by Sandia's Department 6331
NMSU	New Mexico State University
MTA	Magnetometer Towed Array
MTADS	Multi-sensor Towed Array Detection System
NRL	Naval Research Laboratory
RB-11	KAFB Radioactive Burial site number 11
Sandia	Sandia National Laboratories
STI	Search Technologies Inc.
STOLS	Surface Towed Ordnance Locator System
TA-2	Sandia's Technical Area 2
TTP	Technical Task Plan

Executive Summary

The U.S. Navy's Surface Towed Ordnance Locator System (STOLS) was designed and built as a proof-of-principle system to evaluate the utility of an automated, magnetometer-based system to locate buried ordnance. This geophysical system was first fielded in FY 1990.

This report documents DOE-funded activities that have adapted STOLS to meet DOE needs for a "... better, faster, safer and cheaper ..." system for characterizing inactive hazardous waste sites.

In December of 1991 the original STOLS was used to characterize buried wastes at three Sandia landfills located near Albuquerque, NM. Although the surveys were successful, a number of system weaknesses were identified. Coincidental with these surveys, the DOE Office of Technology Development was seeking better technologies to characterize DOE waste sites. Utilizing DOE funds, the Naval Research Laboratory, Sandia, Geo-Centers Inc., NMSU and others worked together to adapt STOLS to meet the DOE need for "... non-invasive detection and quantification of subsurface waste forms ... rapid, large area coverage (acres/day) ... sufficiently mature technologies that the transfer to ER could occur rapidly." DOE-funded activities were conducted under the title of the MTA.

During FY 1993 the existing microwave-based navigation system was replaced with a DGPS-based navigation system. To provide field truthing, a number of known calibration targets were buried in a Cold Test Pit at Sandia. Geo-Centers Inc. independently built a commercial version of STOLS which is marketed as the Search Technologies Inc. (STI) unit. DOE-funded components were tested utilizing the Geo-Center's STI platform. In September of 1993 the system was very successfully demonstrated at an Air Force mixed waste landfill near Albuquerque, New Mexico.

Better software for analyzing MTA data from landfills was developed during FY 1994. The utility of deploying other sensors on the existing platform was explored and two large mixed waste landfills at Los Alamos National Laboratory were surveyed in FY 1994.

The FY 1995 efforts were to have focused on the deployment of other sensors on the existing platform and publicizing the utility of the MTA. Due to other DOE priorities, funding was terminated in early FY 1995.

The MTA, as currently configured, is a vehicle-towed sensor system that measures the strength of the Earth's magnetic field while traveling at speeds of 5 to 15 mph. Information from satellites is used by the Trimble 4000 SSE DGPS to provide the

location of the moving system every second. Seven cesium vapor magnetometers are mounted on a ten-foot wide platform; each magnetometer takes 20 measurements per second. This rate provides about 70,000 measurements per acre (at 5 mph) or one measurement for every 1.5 square feet. The data are then automatically processed to provide on-site, high resolution maps which show the locations and magnetic characteristics of buried objects. On an open smooth site, the MTA can survey about 15 acres per day, collecting over 1,000,000 location-correlated measurements of the strength of the magnetic field.

The MTA provides a significant number of benefits as compared to conventional, hand-carried magnetometer surveys. First, the MTA provides an order of magnitude greater resolution than conventional technology. The higher resolution has three advantages over conventional technology:

- A. The high data density allows better horizontal resolution; for example, the boundaries of burials cannot be accurately estimated using data collected on ten-foot centers.
- B. The finer grid provides data redundancy; a single erroneous data point may be impossible to recognize when data have been collected on five- or ten-foot centers.
- C. Data collected on a fine grid can be quantitatively interpreted using computer algorithms; such analysis is not meaningful when applied to conventional low density data.

Second, the MTA provides near real-time data analysis, allowing on-site alterations to the survey plan. Current technology requires a minimum of one day turnaround for data analysis. Third, the automated nature of the MTA allows surveys of over 15 acres per day with permanent documented records.

Additional development of the system, as the Multi-sensor Towed Array Detection System (MTADS) continues with DoD funding. MTADS is being developed to include chemical and electromagnetic sensors to meet the needs for site characterization and remediation of buried hazardous waste and buried ordnance.

Since funding was terminated in January of 1995, this document is a history of the MTA Program created from existing Sandia word processing files, rather than a true "bottoms up" summary of efforts spanning five years.

In summary, this project includes:

- 1. DOE National Laboratory teaming with private industry and universities;
- 2. Teaming between DOE and DoD Laboratories;
- 3. Adaption of defense technology to solve environmental problems, and
- 4. The application of DOE funds for environmental cleanup research.

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1.0 Introduction

1.1 The Buried Hazardous Waste Problem

A very significant number of U.S. Department of Energy (DOE) Environmental Restoration (ER) Program waste sites involve the assessment and cleanup of buried wastes. The assessment of these buried wastes requires collecting site-specific field data to determine if the site poses an unacceptable threat to human health, and to aid in the selection and design of remedial measures. This field data can be collected using both intrusive and non-intrusive methods. Intrusive methods, such as boreholes, provide direct information about subsurface conditions (e.g., the concentration of solvents in soil at depth). Non-intrusive methods, such as metal detectors, provide information which can be used to infer subsurface conditions.

Some amount of information from intrusive or direct investigations is almost always required for making decisions concerning human health. Unfortunately, intrusive assessments can result in greater risks to on-site workers, maybe slow, provide only point measurements and are expensive.

Non-intrusive methods result in less risk to site workers, are typically rapid, can be used to measure larger areas, and are relatively inexpensive. One of the more important tools for characterizing buried wastes is a magnetometer. A magnetometer measures the Earth's natural magnetic field, which is altered by buried, ferrous materials. A magnetometer survey is completely passive (i.e., emits no energy) and non-intrusive. Magnetometers can detect buried tanks, buried pipes, buried ferrous wastes and have been successfully used at chemical waste landfills (where crushed drums were disposed of in the disposal pits).

Conventional technology requires a person to walk a grid and take magnetometer measurements by hand. The data are then transferred to a contouring package for plotting. The resulting plots are then visually interpreted. A typical survey grid is ten feet by ten feet or greater, with survey rates of an acre or two per day. The time consuming nature of the survey usually prevents large areas from being surveyed (e.g., outlying burials maybe missed). Furthermore, the coarse grid does not allow the boundaries of burials to be adequately determined and may miss small, isolated targets. The conventional method also does not allow for infield decision making.

A magnetometer-based proof-of-principle instrument for detection of buried ordnance was built by the U. S. Navy. The Surface Towed Ordnance Locator System (STOLS) was first fielded at Naval bombing ranges in fiscal year (FY) 1990. STOLS was developed by the Navy Explosive Ordnance Disposal (EOD)

Tech Center and the Naval Research Laboratory (NRL), with sponsorship from the Army Corps of Engineers. Much of the engineering support for the development and testing of STOLS was provided by Geo-Centers Inc.

The proof-of-principle STOLS consisted of seven cesium vapor magnetometers mounted on a low magnetic signature trailer and towed by an all-terrain vehicle. The original system included a microwave-based locator system, automatic data acquisition, and associated software for data reduction and interpretation.

In December of 1991, the proof-of-principle STOLS was used to characterize buried wastes at three Sandia National Laboratories (Sandia) landfills (the Radioactive Waste Landfill, the Classified Waste Landfill, both in Technical Area 2 (TA-2) and the TA-3 Chemical Waste Landfill). Figure 1 shows the prototype array as it was employed at Sandia landfills in December of 1991. With a 1.5-foot spacing between magnetometers and each magnetometer taking 20 measurements per second, the effective survey grid at 5 mph is 0.4 feet by 1.5 feet.

Figure 2 is the original graphic output from the STOLS survey of Sandia's Radioactive Waste Landfill in TA-2. The fence posts associated with the radioactive landfill were cut at ground level creating ideal reference markers for the STOLS survey. Although STOLS was driven in fairly straight lines, the resulting imagery appears wavy, due to the failure of the navigation system to correctly locate itself. This image was "manually" corrected prior to presentation in the final report (Figure 3).

Figure 4 shows the same area as in Figures 2 and 3, except in black and white aerial perspective. A significant number of burials not evident to the unaided eye can be located using the STOLS image. This survey is discussed in greater detail later in this report.

As can be seen in the attached figures, the results of the STOLS survey of Sandia landfills were outstanding, although weaknesses were identified. Most significant was the lack of data interpretation software for "extended" targets and the failure of the existing microwave-based automatic locator system to work near the metal buildings and chain-link fences in TA-2.

1.2 The Need for Better Technology

Coincidental with the survey of TA-2, the DOE Office of Technology Development (DOE/OTD) was seeking "... better, faster, safer and cheaper ..." technologies to characterize and remediate DOE waste site problems. The DOE/OTD program was divided into programmatic areas, such as buried wastes, tanks and mixed wastes. The needs statement of DOE's Mixed-Waste Landfill Integrated Demonstration

Figure 1 - Photograph of the proof-of-principle
STOLS surveying Sandia's TA-2 in December of 1991
3/4

Figure 2 - Original image of anomalies in the Earth's magnetic field of approximately 7 acres in the eastern quarter of TA-2.
5/6

Figure 3 - Image of the same area as Figure 2 except for scale change and the image has been corrected to compensate for problems with the locator system.

Radioactive
Landfill

N

DIGITAL PHOTO by Still Photo 3153-1

Figure 4 - An aerial photo of the same area as covered in Figure 3.
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(MWLID) Program sought "... non-invasive detection and quantification of subsurface waste forms ... rapid, large area coverage (acres/day)."

Sandia, NRL and Geo-Centers Inc. submitted a proposal and were subsequently funded to adapt the STOLS technology to meet the DOE needs for better, faster, safer and cheaper technologies to characterize buried wastes. This report summarizes those efforts.

1.3 STOLS, MTA, the STI system and MTADS

STOLS, MTA, the STI system and MTADS are four different names that could be applied to the same system. The original concept, STOLS, was built as a proof-of-principle system to evaluate the utility of an automated, magnetometer-based system to locate buried ordnance. This same system was utilized to characterize a number of Sandia hazardous and radioactive waste sites in 1991. Adaption of STOLS to meet DOE needs was done under the title of the Magnetometer Towed Array (MTA). The MTA is more descriptive of the original system and was also chosen to separate the DOE-funded activities from the original ordnance-based system. The Geo-Centers commercial unit is marketed as the Search Technologies Inc. (STI) system. Lastly, NRL recognized the utility of deploying other sensors on the same platform and coined the term MTADS for Multi-sensor Towed Array Detection System. As an example of the possibilities, in FY 1994, MTADS testing was conducted with the STI platform utilizing DOE funding for the MTA. We have tried to separate STOLS, STI, MTA and MTADS in this report, however, as the above example indicates, the distinction is not always clear.

1.4 What is the MTA Technology

The MTA is a vehicle-based system which tows a ten-foot wide trailer containing a number of geophysical sensors. Data are collected automatically and the location of the roving system is provided once per second by a differential global positioning system (DGPS). Integral to the system is dedicated data analysis software.

As currently configured, the system contains components of the commercial STI system and components developed and acquired under the MTA program. The sensor suite incorporates an array of seven cesium vapor total field magnetometers, Model 822 from Geometrics Inc. The sensors are mounted on a low magnetic signature, ten-foot wide tow platform developed by Geo-Centers Inc. and towed by the tow vehicle ("dune buggy"). The tow vehicle was developed by Chenoweth Military Products Inc. and modified by Geo-Centers to reduce magnetic self-signature. Data from the sensors are collected at 20 Hz by a 486 PC mounted on the trailer. The data is formatted and passed on to the Main Control Computer

(also a 486 PC) located in the tow vehicle. A reference station is statically located in a magnetically clean area. A proton procession magnetometer, model 856 from Geometrics is used as a reference station to monitor the natural time variations in the Earth's magnetic field. This data on the background magnetic field is transferred to the Main Control Computer after the survey.

The navigation system uses two Trimble, Model 4000 SSE units. One unit operates from a static position, broadcasting pseudo-range corrections via a radio frequency link to the roving unit mounted in the tow vehicle. The Trimbles provide position information at 1 Hz. The data from the magnetometers and the position information are both time correlated. Additionally, the system can record landmark data using a cable and detachable antenna.

For NRL activities, data analysis is provided by a Silicone Graphics (IRIS Indigo) work station, a 486 PC for data transfer and support functions, and laser and color printers. Targets can be analyzed using a three-dimensional model matching code. The simulation code uses an iterative least-squares procedure for matching field data to individually modeled dipoles in the far field. Far field means that the dimensions of the buried object are small compared to the distance from sensor to the buried object. This point dipole model assumes that all targets are single points of varying depths and masses. These simulated point dipoles are placed at various subsurface locations and given various sizes; surface responses are simulated based on these target characteristics. This process is repeated until the best match is found between the simulated response and the actual field data. Targets are quantified in terms of location (x,y,z) and mass. This code, however, can not analyze multiple targets (e.g., waste in a large trench or pit). Software development more appropriate for analysis of buried wastes is discussed later in this report.

The system collects magnetometer data at a rate of 20 times per second from each of seven magnetometers, time-correlates that data to the position data provided by the DGPS, while being driven over the site at speeds up to 15 mph. A dedicated system then provides a variety of data analysis and data presentation options.

1.5 The Benefits of the MTA

The MTA provides a significant number of benefits as compared to conventional, hand-carried magnetometer surveys. First, the MTA provides an order of magnitude greater resolution than conventional technology. The higher resolution has three advantages over conventional technology:

- A. The high data density allows better horizontal resolution. For example, the boundaries of burials cannot be accurately estimated

- using data collected on ten foot centers.
- B. A finer grid provides data redundancy; a single erroneous data point may be impossible to recognize when data have been collected on five or ten foot centers.
 - C. Data collected on a fine grid can be quantitatively interpreted using computer algorithms; such analysis is not meaningful when applied to conventional low density data.

Second, the MTA provides near real-time data analysis, allowing infield alterations to the survey plan. Current technology requires a minimum of one day turnaround for data analysis. Third, the automated nature the MTA allows an order of magnitude more area to be surveyed per day with a permanent documented record. The ability to survey large areas is very important for locating outlying burials; the FY 1992 survey of Sandia sites located several important burials outside the known landfill areas.

Finally, the MTA system provides an excellent platform for the automated collection of data from other types of sensors (such as electromagnetic-based metal detectors).

1.6 Limitations of the MTA

Although the MTA is a wonderful system, there are important limitations. The MTA does not actually image buried hazardous wastes or even ferrous materials; the MTA images anomalies in the Earth's magnetic field. In many cases, these anomalies provide a very useful approximation for locating and characterizing buried hazardous wastes.

No single geophysical technique is universally applicable at all waste sites. Multiple geophysical techniques which complement each other (i.e., respond to different phenomena) are typically employed. The best geophysical investigation scheme will depend on the site setting, budget, required levels of confidence and types of wastes.

2.0 How a Magnetometer Detects Buried Objects

At all points on the Earth there exists a permanent, measurable magnetic field which results primarily from the Earth's rotation about its large ferromagnetic core. We simplistically picture this phenomena as being represented by a set of magnetic field lines emerging from the south pole, flowing around and through the earth and back into the north pole. In the mid-latitudes of the United States we can visualize

these magnetic field lines intersecting the earth's surface at some angle, say 65° as measured from horizontal. The horizontal component of these field lines is more-or-less oriented north-south; the needle of a magnetic compass aligns itself with the horizontal component of this field. The vertical component of the field is not registered by a conventional compass.

The Earth's magnetic field at any point is a vector quantity; the field is characterized by both direction and intensity. The common unit of measurement for the intensity of the magnetic field is the gamma. The intensity of the Earth's magnetic field slowly varies from approximately 70,000 gamma near the poles to about 25,000 gamma near the equator. At the poles the magnetic field lines are approximately vertical and at the equator the magnetic field lines are approximately horizontal.

In most undisturbed areas, over small distances, the Earth's magnetic field lines are uniformly spaced and aligned in the same direction. A secondary magnetic field is induced when a ferrous object is placed in this uniform, primary field. The merging of the primary and secondary magnetic fields "disturbs" the uniform primary field, resulting in areas of lower and higher magnetic field strength. Therefore, objects do not need an intrinsic magnetism to be detected by a magnetometer because the Earth's magnetic field creates an induced field in any ferrous object. This induced magnetic field is 0.1% to $\approx 10\%$ as strong as the primary field and can typically be detected by a magnetometer at the Earth's surface.

In simple terms, neither the Earth's surface nor the air alter the primary magnetic field. If we could see only the magnetic field, it would be fairly uniform and the boundary between the Earth's surface and the atmosphere would not exist. A ferrous object would create an inclusion in this otherwise uniform field. The inclusion would be characterized by both changes in the direction of the magnetic field lines and the intensity of the total field. For this work, we use magnetometers to measure the strength of the magnetic field in a single plane parallel to the Earth's surface.

Local concentrations of certain minerals and the Sun's activity also influence the Earth's magnetic field. Local concentrations of magnetic minerals may create magnetic anomalies as large as several hundred gamma. Sunspot activity, associated with solar magnetic storms, can cause tens to hundreds of gamma changes in the Earth's magnetic field over time scales of seconds to hours and can mask anomalies associated with buried ferrous materials.

To compensate for the Sun's influence on the Earth's magnetic field, an eighth reference magnetometer is set up in a location known to be free of ferrous materials. The reference magnetometer measures the baseline time-varying field which is then subtracted from the survey magnetometer data. Because the

baseline field is subtracted, the MTA images only anomalies in the magnetic field.

Magnetometers cannot "see" beneath the ground. However, by using a magnetometer to measure the strength of the magnetic field at the surface, we can infer what is beneath the ground. For a small isolated target, the anomaly in the magnetic field (measured at the surface) has two lobes, one lobe of greater than background magnetic strength and one lobe of less than background strength. Using a dipole model we can interpret this anomaly and estimate the location, ferrous mass and depth of the buried object. As discussed later, complex objects (i.e., a trench full of wastes) cannot be quantitatively interpreted with a simple dipole model.

3.0 The Original Department of Defense STOLS

On a yearly average, about 200,000 acres of Department of Defense (DoD) bombing and target ranges are decommissioned for civilian control or other DoD uses. The decommissioning process is very labor-intensive, requiring individuals to walk (i.e., survey) large areas with hand-held instruments prior to rendering the area safe and physically cleaned up. The STOLS was designed and built as a proof-of-principle system to provide rapid, automated surveys of bombing and target ranges.

STOLS was jointly developed by the Navy Explosives Ordnance Disposal Technology Center and the NRL, with sponsorship from the Army Corps of Engineers. Primary R&D support was provided by Geo-Centers Inc. of Newton, MA. This proof-of-principle STOLS was previously described.

At the end of each STOLS survey, data recorded by the onboard computer were combined with data from the reference magnetometer and transmitted to the data-processing computer. During data processing, the navigation data were correlated with reference magnetometer data and a magnetic-anomaly image map was created. Magnetic-anomaly information was interactively analyzed. During computer analysis, the system interactively analyzed the magnetometer data and generated the best-fit interpretation based on the perceived magnetic dipole signature. Targets were categorized by depth, size and coordinate. The proof-of-principle system was first fielded in FY 1990 (Naval Explosive Ordnance Disposal Technology Center, 1991).

To prove that the system had a much wider range of application than just locating buried bombs, STOLS was used to survey a number of inactive waste sites at Sandia's Technical Areas 2 and 3, located near Albuquerque, NM.

4.0 STOLS Survey of Sandia's TA-2

Sandia's TA-2 is a diamond-shaped area, approximately 1450 feet on a side and encompasses 45 acres. The area is surrounded by a ten-foot high chainlink fence and had guard towers at each corner and in the center.

TA-2 was constructed in 1948 by Los Alamos National Laboratory as the United State's first production assembly area for nuclear weapons. Through the early-1950's the majority of this country's nuclear weapons stockpile was assembled in TA-2. Weapons assembly work in TA-2 ceased in the mid-1950's, and for the past 40 years, the major activities in TA-2 have involved the development and testing of explosives and explosive devices. As an engineering note, some of the walls in the original assembly buildings are 14 feet thick.

A total of 19 inactive hazardous waste sites or Solid Waste Management Units (SWMUs) had been identified in and around TA-2.

The only entrance gate into TA-2 is at the western apex and the buildings are located along a line from the northern apex to the southern apex. The eastern corner is behind the buildings and was used as a "back 40" for waste disposal.

The Radioactive Waste Landfill was closed in 1959 and covers about 0.3 acres of the northeast corner. The landfill was apparently used from 1949 to 1959. The burial log no longer exists and information collected from interviews of long-time employees indicates that the wastes were predominately solids with some liquids.

Conflicting information was obtained from longtime employees concerning a former Chemical Waste Disposal Pit. Some interviewees felt that a separate pit within the Radioactive Waste Landfill was used for the disposal of chemicals, whereas others thought that there might have been an additional landfill in the northeast corner of TA-2 for the disposal of chemicals. A third area of concern was identified on a 1963 sketch map which indicates that wastes from a non-Sandia facility were buried in the northeast corner of TA-2. Only the sketch locations are available; the exact locations and the nature of the wastes is unknown.

A conventional geophysical investigation was originally planned for portions of TA-2. In developing the conventional geophysical investigation plan, information from the 1963 sketch map was used in selecting the search target, which had an assumed diameter of six feet. Other specific assumptions included: no more than a 1-in-20 chance of missing the assumed target (metallic wastes, six feet in diameter and buried four feet deep); with specific soil conductivities and specific footprints of measurements for specific geophysical tools. Based on these

assumptions, a 5.5 foot x 14 foot geophysical search grid was selected. This grid would require approximately 7,700 individual measurements for the 14 acres of interest. These thousands of points would have to be land surveyed and staked, then measurements would be recorded with geophysical instruments and the data would have to be transferred to analysis software.

Geo-Centers Inc. approached local DOE representatives with a number of technologies they were developing or associated with. These technologies included fiber optic sensors, miniature magnetometers and geophysical "towed arrays." One of the towed arrays consisted of four ground penetrating radar antenna/receivers and the other system, STOLS consisted of seven total field magnetometers. This technology seemed far superior to the proposed 7,700 individual measurement and Sandia approached NRL & Navy EOD Tech Center to determine if they would be interested in surveying hazardous waste sites with STOLS.

The advantages of a STOLS survey at Sandia waste sites were numerous: only the locations of the microwave transmitter/receivers would be surveyed; several acres per day could be surveyed and the burial sites would be located and partially characterized. Prior to the undertaking the STOLS survey at Sandia, a preliminary survey was undertaken in July of 1991 using handheld instruments. The outcome of the preliminary survey was favorable and a STOLS survey was planned for the Fall of 1991.

Site preparation activities were undertaken after the July 1991 trial survey and the fence around the Radioactive Waste Landfill was temporally removed. To minimize soil disturbance, the steel fence posts were cut at ground level; the stubs of these posts provide excellent data reference points. A wooden post was installed at each of the four corners of the entire northeastern area; these posts later would hold the microwave transmitter/receivers. A Health and Safety Plan for working on a radioactive/chemical waste site was written. The plan was approved as having met the requirements of Sandia's Industrial Hygiene for chemical concerns (per 29 CFR 1910.120) and Health Physics for radioactive materials concerns.

The STOLS survey was conducted during the first two weeks of December 1991. Although four areas were surveyed, only the details of one are discussed here. The other three areas were the Classified Waste Landfill in TA-2, the west-central portion of TA-2, and the Chemical Waste Landfill in TA-3. One of the two weeks was lost to weather and equipment problems. The equipment problems were anticipated since STOLS was a prototype system, not a field-hardened commercial unit. The most confounding problem involved the sporadic operation of the automatic microwave-based locator system. The RACAL Inc. locator system, which had functioned acceptably well at open bombing ranges, apparently was confused either by radar from low flying aircraft, mobile telephones, nearby high-

voltage power lines, or its own microwave echoes from the numerous chainlink fences and metal buildings. As a result of these navigation problems, confidence in the absolute location of magnetic anomalies is high near known magnetic landmarks and decreases with increasing distance from those landmarks.

In addition to STOLS, a sister system, based on ground penetrating radar (GPR) was also fielded. This system consisted of four GSSI 300 MHz GPR antennas, each mounted on a sled which was pneumatically held against the ground as the system was driven over the survey area. This system is described in detail in the reference cited later in this section. Despite the pneumatic system designed to hold the antennas against the ground, every major bump or rock caused the system to momentarily decouple and image quality was greatly compromised. GPR was never seriously considered again for STOLS\MTA\MTADS development.

By the end of the second week, all four areas had been surveyed. Figure 3 presents one of the final images from the northeastern corner of TA-2. Figure 4 shows the same area in black-and-white aerial perspective. *A significant amount of intuitively appreciable information not evident in the aerial photograph can be interpreted from the STOLS images.*

Illustrated in Figure 3, the horizontal anomaly across the bottom of the image and the diagonal feature across the middle of the image correspond to old roadbeds and were interpreted as either magnetite-bearing sands or large, abandoned cableways or both.

Of equal importance are the areas of background magnetic intensity; we now know with great confidence where ferrous materials were not buried. As can be seen in the attached figures, the results of the STOLS survey of the northeast area of TA-2 were outstanding. Results of the survey of Sandia hazardous waste sites are presented in detail in Naval Research Laboratory, 1992.

On December 10, 1991 a meeting was held to discuss the application of the STOLS technology to Sandia hazardous waste sites. John Cochran and Jim McDonald provided relevant information to individuals from Los Alamos National Laboratory, the DOE, Ecology and Environment Inc., GRAM Inc, the U.S. Geological Survey, ARA Inc. and numerous Sandia employees.

LIMITATIONS

The failure of the microwave-based locator system was the greatest weakness discovered during the survey. The system that had functioned acceptably well during surveys of open bombing ranges was almost inoperable inside TA-2. Only by manually correcting the survey paths were acceptable images obtained, and

then the absolute accuracy was greatly compromised.

Additionally, the algorithms used in the automatic data-interpretation software were written for characterizing point targets (i.e., bombs) and were not applicable for analyzing large burial sites. Survey areas containing large burials had to be analyzed manually.

5.0 Department of Energy Needs

New and innovative technologies were needed to offset the estimated 150 to 200 billion dollars to assess and remediate the DOE waste site problems. Sandia, NRL and Geo-Centers Inc. submitted a proposal to adapt the STOLS technology to meet the DOE needs for innovative technologies. The 1992 proposal made the following points:

- (1) DoD has funded the entire cost to develop the existing magnetometer towed array system;
- (2) STOLS demonstrated great potential as a system to characterize buried wastes; however,
- (3) Weaknesses were identified including the failure of the existing microwave-based automatic locator system, the lack of data interpretation software, and the need for near real-time data display, and
- (4) DOE funds could be used to correct the weaknesses in existing system and adapt the system for characterizing buried waste sites.

Proposals were written and submitted to both the DOE/OTD Buried Waste Integrated Demonstration at the Idaho National Engineering Lab and the MWLID Program at Sandia. The MWLID's mission was to demonstrate and transfer to the ER Program, in-situ characterization and remediation technologies for landfills in arid environments that contain a complex mixture of metal, organic and radioactive wastes.

Through the MWLID Program, funds were received for FY's 1993, 1994 and 1995. Those MWLID-funded activities are summarized in the following sections.

6.0 FY 1993 Activities

6.1 Introduction

The FY 1993 efforts were focused on: (1) Integrating a new navigation system to replace the microwave-based navigation system that had failed at TA-2; (2) modification of interpretation algorithms to meet waste site characterization needs, and (3) demonstrating the MTA at an MWLID-designated landfill. To provide a data set for testing the extended target algorithms, several known targets were buried at Sandia. Each of these topics is discussed in the following text. A detailed, month by month progress report is provided in the Appendices under "FY 1993 Monthly Highlights." An overview of the FY 1993 funding is provided in the Appendices under "Funding Summary."

6.2 Global Positioning System

An integral component of the MTA is the navigation system which provides real-time location data while the survey system moves at 5 to 15 mph. This location data is time correlated with data from the survey instruments and may be used to keep the survey vehicle on track.

The navigation system incorporated into proof-of-principle STOLS was microwave-based, consisting of four stand-alone beacons with the receiver hardware located on the STOLS platform.

As part of the MWLID-funded efforts, a new navigation system would be selected, purchased and integrated. A trade study was conducted by the NRL to identify competing technologies and possible vendors. Systems based on microwave range-range, acoustic, laser and DGPS were considered. Potentially interested vendors were widely solicited and invited to demonstrate their capabilities at a test track prepared by the NRL. The test track was setup by NRL at the NRL Chesapeake Beach Detachment, Chesapeake Beach, MD. Field evaluations began the week of February 15, 1993.

The field trial survey site consisted of two types of survey courses. About half of the course consisted of a grid pattern on relatively flat, open and level terrain with a good view of the sky. The other half of the course, the road course, had significant altitude changes, intervening tree lines, large metallic structures and fences, requirements for sighting over buildings and obstructions and some limitations of sky visibility. Seven first order geodetic monuments were set around the site.

Companies demonstrating range-range systems were provided with the base station coordinates. NRL provided the survey vehicle and a driver to standardize some of the irrelevant variables. A demonstration survey consisted of a static survey to provide fixed point accuracy and a moving survey of the grid and road courses to provide dynamic point accuracy.

A number of vendors, including those who sell laser and acoustic systems, declined to participate either because of performance requirements or because of scheduling or cost constraints. Eight companies participated and presented microwave range-range systems or DGPS systems. Two companies tested both types of instruments. Including the Trimble Portable, ten navigation systems were tested.

The test results were presented as four types of survey image plots. These provide a visual demonstration of noise level, data drop outs and system performance and accuracy. The post processed GPS data from those vendors who post process are presented separately and compared with the real-time DGPS data.

This test provided a comprehensive evaluation of the systems presented; to our knowledge, these systems represented state of the art technologies in both microwave and DGPS navigation systems in 1993. In summary, eight vendors of locator systems demonstrated their ability to locate targets on the test track while driving through the test track at over 5 mph. Some vendors demonstrated real time 100% accuracy at ≤ 1 meter error, and 100% accuracy at ≤ 0.5 m. error in post processing. Other vendors were less than 10% accurate. The performance of these eight navigation systems and the test setup are discussed in detail in McDonald *et al.*, 1993.

Based on these tests, the \$100 K Trimble Navigation 4000 SSE DGPS system was purchased for incorporation into the MTA. The Trimble system was not incorporated into the aging proof-of-principle STOLS platform, but was incorporated into the commercial STOLS platform being built by Geo-Centers Inc.

6.3 Commercialization of STOLS by Geo-Centers

Geo-Centers Inc. recognized the tremendous unexploded ordnance and DOE hazardous waste cleanup markets. They also recognized the advantages of STOLS over existing technology and the experience the company had gained supporting the Navy development of the prototype STOLS.

Utilizing internal capital, Geo-Centers Inc. designed and constructed a commercial version of STOLS. The commercial system was oriented towards the DoD ordnance remediation market with the MWLID Program providing an avenue to the

hazardous waste assessment market.

This commercial unit (marketed as STI) provided a robust platform for field demonstration of MWLID-funded efforts. Geo-Centers Inc. greatly compressed their schedule to provide a working system by September of 1993. More than any other factor, the Geo-Centers Inc. efforts during the spring and summer of 1993 contributed to the successful field demonstration of the MTA.

6.4 Creation of the Cold Test Pit in TA-3

One of the shortfalls of the field demonstration at TA-2, and a real concern for the MWLID-funded field demonstration in FY 1993, was the lack of "field truthing." NRL and Geo-Centers were familiar with the interpretation of magnetometry data from former bombing ranges, but were not familiar with the interpretation of data from buried waste sites. Furthermore, New Mexico State University (NMSU) researchers were interested in the "calibration" of the Multi-sensor Analysis Program for Environmental Restoration (MAPER) software (MAPER is discussed later). None of the targets previously identified at Sandia or during the FY 1993 field demonstration could be excavated for field truthing.

The solution was to bury a number of known targets in a magnetically clean area. The targets would be composed of 55 gallon drums, the currency of buried wastes. A total of five target configurations were selected: a single vertical drum; a single horizontal drum; two combinations of multiple drums, and a single sheet of steel, four feet by eight feet by one-half inch thick. The configuration of these targets is defined in Figure 5.

The ideal location of the Cold Test Pit was in the vicinity of the Kirtland Air Force Base's Radioactive Burial Site Number 11 (RB-11) Landfill. There were no special security considerations and the calibration targets would be "adjacent" to the RB-11 Landfill. Because Kirtland Air Force Base controls RB-11 and the surrounding lands, the decision was made to bury the targets on Sandia-controlled land. The Sandia MWLID Program controls the land surrounding the Sandia Chemical Waste Landfill in TA-3, and a site immediately southeast of the Chemical Waste Landfill was selected for the burial of the calibration targets.

Bob Floran (Sandia, MWLID Program) paid for the burial of calibration targets with existing MWLID funds and Bob Helgesen (Sandia, MWLID Program) helped coordinate the burial of the targets. However, it was Jim Swanson (Sandia, MWLID Program) who took "ownership" for the burial of the calibration targets - without Jim's initiative and knowledge of Sandia, the calibration targets could not have been buried in time for the field demonstration. Figure 6 is a photograph of the burial of some of the targets.

Figure 5 - Schematic of targets buried in Sandia's Cold Test Pit.

In retrospect, the greatest weakness of the Cold Test Pit was that no measurements were made to determine if there was significant residual magnetism in any of the buried targets. Steel, especially when heated to melting or near melting (e.g., through welding) assumes a permanent magnetism which is related to the orientation of the object in the Earth's primary magnetic field at the time the steel is heated.

Figure 7 is an MTA image from the Cold Test Pit (courtesy of Sunbelt Geophysics). The Cold Test Pit ultimately provided calibration data for the FY 1993 field demonstration, calibration for the Sandia ER Program (personal communication David Hyndman, Sunbelt Geophysics), and the truthing for Dr. Kim Dalton's dissertation and MAPER development.

6.5 Data Analysis and MAPER

Magnetometer data are typically analyzed qualitatively (Hempen and Hatheway, 1992). In performing qualitative analysis, the geophysicist mentally merges prior geophysical experience with site specific information. Such interpretations are usually provided in relative terms such as large or small. Qualitative interpretations are not necessarily repeatable as three geophysicists may provide three different interpretations of the same data.

Quantitative analysis provides a number of very important advantages over qualitative analysis. First, targets can be quantified. Ambiguous descriptions like "a large and fairly deep burial near the northwestern edge of the landfill" are replaced with quantitative descriptions like "300 kilograms of ferrous materials buried 2.5 meters deep at 35° 0.40737 latitude and 106° 31.10213 longitude." Threshold criteria (e.g., excavate only targets greater than ten kilograms) can then be applied to site cleanup. Second, numerical analysis allows the user to interpret or "see" target boundaries instead of the magnetic dipole expression of targets. Third, and very important for quality control, numerical analysis can be reliably repeated. Finally, numerical analysis is an important tool in the data interpretation tool chest; numerical analysis should never be viewed as the only tool in the tool chest.

Quantitative analysis of magnetometer data has typically been limited to the *two-dimensional matching of profiles* where an idealized magnetic response profile is compared to the profile obtained from field magnetometry data (MacLean *et al.*, 1991).

For simple magnetic anomalies (i.e., anomalies that image as paired positive and negative anomalies in the magnetic field), computers allow three-dimensional model matching, where the *three-dimensional distribution of magnetometer values* from a

Figure 6 - Photograph of the burial of targets in the Cold Test Pit
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field survey are compared to the spatial distribution of values from an assumed target.

The magnetometry data collected by STOLS at TA-2 in 1991 were analyzed using a three-dimensional model matching code employed by the NRL. The NRL/STOLS simulation code uses an iterative least-squares procedure for matching field data to individually modeled dipoles in the far field. This point dipole model assumes that all targets are single points of varying depths and masses. This assumption is a reasonable approximation for a buried 500 pound bomb. Targets are quantified in terms of location (x,y,z) and mass. Unfortunately most targets at landfills are not well approximated as single points and do not image as dipoles in the far field.

For the characterization of buried wastes, (i.e., for the DOE needs), the interpretation of "extended targets" not point targets is important. Numerical methods were needed to interpret magnetometer data with respect to clustered or extended targets for the purposes of guiding further site investigations (e.g., drilling or trenching) and for estimating the volume of wastes to be excavated, treated or capped. Therefore, the goal of these efforts was to develop methods to estimate location, size and shape of extended objects based on surface observations of the total magnetic field.

Why it is Difficult to Interpret the Signature from Extended Targets

Magnetometers cannot "see" beneath the ground. However, by using a magnetometer to measure the strength of the magnetic field at the surface, we can infer what is beneath the ground. When multiple targets are placed in a trench or pit, the induced fields add and subtract vectorially depending on the relative locations and orientations of the targets, the mass of each target, the distribution of mass in each target and the magnetic susceptibility of each the target. There is no unique mathematical description or algorithm available which can be used to define the edges and contents of extended burials.

The purpose of this work was to develop an algorithm or a series of algorithms to provide a quantitative description of buried clustered objects. In simple terms, in forward modeling, a physics-based mathematical model is designed to represent an extended burial. Using a computer-driven, physics-based forward model, some of the parameters of a simulated extended burial would be automatically varied; for example, the lateral dimensions might be varied. The outputs from this computer-driven mathematical model are compared to magnetometer data collected in the field. The "interpretation" of the field data is simply the simulated data that best fits the field data (i.e., minimizes the mismatch between the modeled response and the measured field data). Because subsurface characteristics are inferred, not directly measured, multiple complementary tools are typically deployed at hazardous waste sites.

Multi-sensor Analysis Program for Environmental Restoration (MAPER)

Coincidental with the MTA work, Researchers at NMSU were developing pre-commercial, public domain software for analyzing and interpreting data from waste site surveys, including magnetometer data. The Multi-sensor Analysis Program for Environmental Restoration (MAPER) is envisioned as employing three levels of algorithms for analysis of magnetometer data.

1. PickGAD - is the name of the program that quickly picks targets from Geo-magnetic Anomaly Data (GAD) and is based on Breiner's line-by-line analysis of total moment and fall off rate (Breiner, 1973). Given field data, if a mass is assumed, depth can be calculated or vice versa. PickGAD is computationally fast and allows the first "picks" of potential targets.
2. FastGAD - takes place on two levels. The first level uses PickGAD to isolate targets and the second level uses McMahon's method (McMahon and McIntire, 1966) for modeling rectangular boxes.
3. FullGAD - will use data from the second tier FastGAD to initialize a 3-D model match using the magnetostatic Helmholtz equations. In this model, distributed masses and multiple objects are superimposed on each other. This technique requires significant processing time.

At the time of the proposal, work on PickGAD was complete and work on FastGAD had begun. A detailed discussion of this work can be found in Linder (Dalton), 1995.

The Strategy for Quantitative Analysis of Extended Targets

For the quantitative interpretation of extended targets, a five part, two year strategy was developed. The goals for FY 1993 were: (1) distribute a Statement of Work relative to the extended target problem; (2) solicit proposals from parties experienced in the quantitative interpretation of magnetic data, and (3) setup and collect data from a calibration area (i.e., the Cold Test Pit). Then, in FY 1994, (1) review and fund the best approach(es) and (2) test the numerical approaches using the data from the Cold Test Pit. As discussed under the Landfill Characterization and Monitoring System (LCMS), feedback from the testing (i.e., comparing simulated results to actual targets) was used to further refine the MAPER codes.

With Sandia input, the NRL developed a Statement of Work requesting proposals for better numerical approaches for interpreting magnetometer data from extended magnetic targets. Proposals were solicited from three parties experienced in writing algorithms to interpret high density magnetometer data. The three parties were Dr. Ed Hensel (NMSU), Geo-Centers Inc. and Orincon. The other FY 1993 activity, burial of calibration targets was previously discussed.

6.6 Field Demonstration at Radioactive Burial No. 11

Field demonstrations were a key component of the MWLID Program and two locations were considered for the FY 1993 field demonstration, the DOE Rocky Flats Plant near Denver, Colorado and the Kirtland Air Force Base's Radioactive Burial Site No. 11 located near Albuquerque, New Mexico. In the Fall of 1992, John Cochran and John Stormont (Sandia, MWLID Program) met with Brook Wilson of Environmental Research and Technology, EG&G Rocky Flats and discussed the possibility of fielding the MTA at select Rocky Flats ER Program sites.

Rocky Flats was very interested in fielding the MTA. Through Brook Wilson, Rocky Flats would provide support (paperwork, site preparations, security escorts ...) but no additional funding was available. Operable units 2 and 5 were considered for an MTA survey.

The other location was the Kirtland Air Force Base's RB-11 Landfill which is a mixed waste landfill located near a number of Sandia facilities. A conventional magnetometer survey was conducted at RB-11 in 1988. Results from this conventional survey could be contrasted to the results from an MTA survey for a comparison between conventional and the innovative magnetometry surveys. Through an agreement with the Air Force, a number of MWLID technologies were being demonstrated at RB-11. The proximity to Sandia facilities, the previous conventional magnetometry survey, and the onsite support provided by Sandia's MWLID Program tipped the scales to the RB-11 site.

RB-11 Site Description

RB-11 is a 2.5 acre landfill that was used from 1960 to 1971 and is described as containing nine trenches (SAIC, 1985). These trenches are generally oriented east-west and are believed to range in depth from eight to 20 feet, with three feet of cover. No accurate disposal records were kept. The landfill was used primarily for the disposal of contaminated animal carcasses, animal excreta, and associated laboratory wastes. These wastes contain small quantities of hazardous and radioactive materials. Much of the waste is believed to have been contained in 55 gallon steel drums. The landfill was unmonitored and probably received other types of wastes. An unsubstantiated story reports the burial of a 55 gallon drum of contaminated mercury from the Nevada Test Site (SAIC, 1985).

RB-11 is situated on the Sandia-Manzano piedmont plain and is relatively flat. The soils are grass-covered and composed of sandy silt and silty sand. The depth to the water table is approximately 500 feet. The two southernmost trenches have narrow asphalt caps and one trench in the middle of the site has subsided as much as three feet. The edge of a single drum is exposed near the southern end of the

site. There were no fences or known utilities on the site.

Prior to the first survey in 1988, a registered land surveyor used steel rebar to stake the seven corners of the boundary of the landfill. These corners served as a common reference for each of the geophysical surveys.

The first geophysical survey, a conventional magnetometer survey, was completed in 1988 by an environmental consulting firm. Referenced to the seven corners of the landfill, measuring tapes were used to lay out a ten-foot by ten-foot grid. Data were collected at each node using an OMNI IV proton procession, total field magnetometer. Magnetic readings were also recorded several times a day at a base station to determine diurnal variations in the background field values. This survey (IT Corp., 1988) is described in greater detail later in this report.

Preparations for the Survey

In addition to Geo-Centers efforts to complete the commercial STI system in time for the September survey, a number of NRL/Sandia/Geo-Centers activities were necessary to prepare for a successful field demonstration. In April of 1993, a presurvey of the RB-11 Landfill was conducted by a NRL representative using a handheld magnetometer. Numerous metallic targets were located in each trench, although no trench is completely full of metallic targets.

In May 1993, a presurvey of the RB-11 Landfill was conducted by a Geo-Centers, NRL and two vendors using DGPS (Trimble) and microwave-based (Sercel) navigation equipment. Both navigation systems functioned well at the RB-11 Landfill.

The surface of the RB-11 Landfill contained significant clutter (e.g., telephone poles, concrete blocks and portable buildings) that would prevent the successful demonstration of the MTA. MWLID staff coordinated with Air Force personnel to have the clutter removed. In July of 1993 Geo-Centers staff worked with MWLID staff to develop a Health and Safety Plan for the field demonstration and NRL developed the Test Plan for the field survey. The location of the land survey markers from the 1988 survey had been lost and Sandia had the seven corners of the landfill resurvey prior to September. Finally, in September, Sandia staff began negotiations with Los Alamos National Laboratory for a FY 1994 field demonstration at Los Alamos.

MTA Field Demonstration at RB-11

During the week of September 7, 1993 the MTA was successfully demonstrated at the RB-11 Landfill. Equipment was mobilized around September 1, 1993 with the final setup taking place September 6 (Labor Day). The field demonstration

began on the 7th with a radiation screening of the MTA and a Health and Safety Briefing. The DGPS and magnetometer base stations were also setup.

Less than 2 hours was required to actually survey RB-11. Among the findings were:

- (a) previously unidentified, large (one inch in diameter) electrical cables buried across some of the pits at a depth of about three feet;
- (b) the collapsing trench was found to contain almost no metal, and
- (c) one of the northern pits was found to extend much further north than previously believed.

On September 8th, additional surveys were conducted at RB-11, such as varying the height of the magnetometers. Sandia still and video photographers recorded much of the survey and researchers from NMSU were also present to view the field demonstration.

Figure 8 is a photograph of the STI commercial unit at the RB-11 Landfill and Figure 9 is a photograph of the Trimble DGPS base station. Figure 10 is a photograph of team members (identified in the caption).

The Cold Test Pit was surveyed on the September 9th with both the MTA and hand-held equipment. The DGPS-based navigation system and the STI system performed flawlessly.

For details concerning this successful field demonstration, the reader is urged to review Results of a Magnetometer Towed Array Survey and Sub-System Testing at Site RB-11, Kirtland Air Force Base, Albuquerque, NM. (McDonald *et al.*, 1994a).

Public Relations

With Geo-Centers assistance, the field demonstration generated significant press interest. A public demonstration was conducted on September 9, 1993 at the Cold Test Pit in TA-3. The public demonstration resulted in an article in the Albuquerque Journal (September 10, 1993) and stories aired on three local television stations: KOAT-TV on September 10, 1993; KOB-TV on September 28, 1993, and KRQE-TV on November 11, 1993. A Sandia Press Release was developed in the Fall of 1993 which resulted in additional press interest including articles in:

- SANDIA SCIENCE NEWS, February 1994;
- Bishop, 1994 (HAZMAT WORLD);
- ENVIRONMENTAL REMEDIATION TECHNOLOGY, December 1, 1993;
- SANDIA TECHNOLOGY, ENGINEERING AND SCIENCE ACCOMPLISHMENTS, February 1994, and
- TECHNOLOGY TRANSFER BUSINESS, Winter 1995.

Additional Geophysical Surveys of TA-2

In addition to the survey of RB-11, Geo-Centers also participated in additional geophysical surveys of TA-2. This survey was the first commercial survey with STI system. The additional total field magnetometer survey work was needed in areas not covered or poorly covered by the 1991 survey. Approximately 12 acres were surveyed by the STI unit. Results of these surveys are documented in the internal report titled Final Technical Report STOLS Survey at Sandia National Laboratory Technical Area 2, prepared for Lamb and Associates by Geo-Centers Inc., under contract LAI-93-182-002, December 1993.

An EM survey was conducted to complement the magnetometer survey. EM surveys measure the ease of induced current flow in the media surrounding the survey instrument, whereas the total field magnetometer measures the strength of the Earth's natural magnetic field. Approximately 18 acres were surveyed with a Geonics Ltd. EM-61 high resolution time-domain metal detector and/or an EM-31 Terrain Conductivity meter. The EM surveys were conducted by Lamb and Associates.

Historic aerial photographs, soil vapor survey results, and results from the magnetometry and EM surveys was later used by Sandia personal, NMSU and the LCMS project to further refine the MAPER software (discussed under FY 1994 LCMS).

7.0 FY 1994 Activities

7.1 Introduction

The FY 1994 efforts were focused on: (1) developing better methods for interpreting magnetometer data from trenches of buried wastes; (2) a field demonstration; (3) determining the utility of deploying other sensors on the existing platform and, (4) documenting the RB-11 Survey.

A detailed, month-by-month progress report is provided in the Appendices under "FY 1994 Monthly Highlights." An overview of the FY 1994 funding is provided in the Appendices under "Funding Summary."

Cost-Benefit Analysis of the MTA

The DOE/OTD Program contracted with Los Alamos National Laboratory (LANL)

Figure 8 - Photograph of the Geo-Centers commercial STI unit at the RB-11 Landfill.
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Figure 9 - Photograph of the Trimble DGPS base station at the RB-11 Landfill.
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Figure 10 - Photograph of team members. Jim McDonald, center, hat off, NRL,
John Cochran, immediate right of Jim, Sandia, Dick Russell, far right, Geo-Centers Inc.
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staff to conduct a cost-benefit analysis of a number of DOE/OTD-funded technologies, one of which was the MTA. Sandia, NRL and Geo-Centers supported LANL in their analysis of the MTA technology and a draft of the report was completed in mid-December. The report was not transmitted to the Sandia Principle Investigator (Cochran), however, Geo-Centers Inc. received a copy just prior to December 25, 1993. The reports authors and Geo-Centers traded letters over the Holidays culminating in a meeting in Albuquerque in January of 1994. Several issues were discussed including: tone (is the glass half empty or half full); cost of conventional or baseline technology; the utility of the added data density and the number of DOE facilities with more than 50 acres of sites needing magnetometer surveys.

Compromises were worked out and the final report was published in November of 1994. The compromises were not entirely satisfactory and copies of Sandia letters are duplicated in the Appendix of this report. The final LANL report by Bremser and Booth, 1993 concludes that for small jobs, where high-resolution is not important, the MTA is not cost effective. However, for large sites (> 50 acres) or where high-resolution is important, the MTA is the system of choice and the systems high resolution "... may set the standard for such surveys in the future."

7.2 MTADS

No single geophysical technique responds to all types of contaminants and multiple sensors are needed to provide complementary, rapid, high resolution surveys of buried waste sites.

The MTA, with it's automatic data acquisition and navigation system is used to deploy seven magnetometers which measure the total strength of the Earth's magnetic field. This information is interpreted to provide data about buried ferrous wastes. With adaption, this same system could be used to deploy a gang of other sensors to provide the same type of rapid, non-intrusive, large area coverage of hazardous waste sites. This next-generation system has been named the Multi-sensor Towed Array Detection System or MTADS.

A number of sensor technologies were considered for deployment on MTADS. The ideal sensor: (1) responds to phenomena useful in characterizing abandoned waste sites; (2) has detection limits below the levels of concern; (3) takes measurements quickly; (4) is field durable (e.g., vibration, dust, moisture and temperature); (5) is light and compact; (6) does not require large amounts of electricity or gas, and (7) is relatively inexpensive.

The following types of technologies were identified and evaluated against the seven criteria listed above: (1) radiation detectors; (2) infrared scanners; (3) x-ray

fluorescence; (4) electromagnetic (EM) (including metal detectors); (5) magnetometers (total field, gradiometers and three-axis magnetometers); (6) ground penetrating radar; (7) organic vapor analyzers (e.g., flame ionization detectors); (8) air particulate samplers; (9) optical sensors for chemicals in air, and (10) acoustic. Gravimeters were considered but not evaluated since none of the authors were familiar with the use of gravimeters for characterizing landfills. Also several other types of sensors (e.g., fiber optic chemical sensors and mass sensors) were not considered because of their relative newness.

Some of these sensors are passive and measure natural phenomena, such as the strength of the Earth's magnetic field. Other sensors are active and "broadcast" energy and measure some type of response. A number of tools were considered for incorporation into the existing platform. Two sensors which are currently (1995) being assessed by NRL are the Geonics EM-61 and Barringer's SURTRACE™.

EM tools generate an electromagnetic pulse and measure the response to that energy. EM tools can be used to measure the conductivity of the soil surrounding the tool (e.g., a metal detector) and also can measure intensity and time of a return from a pulsed signal (e.g., GPR).

A recently introduced metal detector is the Geonics EM-61; a high resolution, quantitative, metal detection. The EM-61 is a focused instrument which provides high spatial resolution. The EM-61 generates electromagnetic pulses by passing a current through a one-meter square coil, these pulses penetrate the subsurface and briefly induce secondary EM fields. Like all geophysical instruments, this instrument measures contrasting properties. Soil has relatively low electrical conductivity and the secondary field dissipates rapidly. Buried metal is far more conductive and the secondary field persists much longer. The EM-61 measures the strength of the secondary field during the off pulses between the primary pulses. The measurement "window" is delayed to allow the primary soil response to dissipate and only the response of the buried metal is measured.

As discussed under the Survey of Sandia's TA-2, a GPR-based towed array was deployed at a number of Sandia ER Program sites in the fall of 1991. In general, the performance was poor because the sled-mounted transmitters/receivers bounced on the ground and the decoupling resulting in low quality data. Also, data interpretation has always been difficult with GPR. Therefore GPR was not considered for MTADS.

A second sensor currently being assessed is Barringer's SURTRACE™ which collects and analyzes particulates from the lands surface micro-layer. This micro-layer of particles (i.e., dust) is in contact with the atmosphere and is composed of organic and inorganic particles. This layer reflects the geochemistry of the

underlying soils and may also contain contaminants such as heavy metals. Samples of the micro-layer can be collected by dragging a sampling port (i.e., a vacuum tube) across the ground surface. Once collected, these particles are impacted upon a high-purity adhesive tape that is labeled and advanced every few seconds. These samples are then analyzed using the LASERTRACE™ technique in which the sample is vaporized off of the adhesive collecting tape using a laser and carried by an argon stream to an intense radio-frequency plasma. Elements and chemical species carried into the plasma are excited to strong spectral emission and the output is analyzed in a direct reading spectrometer. Analytical sensitivity varies between 10^{-9} to 10^{-14} grams which is sensitive enough to monitor most elements at background levels. The analytical system is automatic and operates on a ten second cycle basis. Such a system could be used to collect samples of the micro-layer as the MTADS traverses a site. The tape coupons would be analyzed at the end of the day. Importantly, the system requires no sample preparation prior to analysis. The NRL is currently assessing the Geonics EM-61 and Barringer's SURTRACE™ for incorporation into MTADS.

7.3 Data Analysis

As discussed under "FY 1993 Data Analysis and MAPER", a two-year strategy was employed to develop methods for the quantitative interpretation of extended targets. In FY 1993 proposals were solicited from three parties experienced in solving the magnetic inverse problem. All three offered some type of graded approach from fairly simple to very computationally intensive (e.g., full 3-D Inverse Modeling). The great variety of proposed approaches, and the lack of a clear and compelling argument for any one approach reflects the complexity of the task at hand.

Ten different approaches were proposed, with work spanning two years at an estimated cost of about 1.5 M dollars. Unfortunately, only 0.07 M dollars were available to support this effort. The proposal by NMSU was the most comprehensive of the three and the most likely to significantly advance the mathematical modeling of extended and multiple targets. Therefore, limited funding was transmitted to NMSU in April 1994 to complete work on FastGAD, which employs a forward distributed dipole model to simulate the surface magnetic response from buried objects. The distributed dipole model assumes all targets to be three-dimensional steel bounding boxes or rectilinear shells with a wall thickness of 1 millimeter. This program is discussed further under in the Appendices under "FY 1995, Comparison of data from EM-61 and the MTA at RB-11" and is discussed in great detail in Kim Dalton's dissertation (Linder (Dalton), 1995).

A detailed evaluation of three proposals is provided in Review and Selection of Proposals to Develop Data Interpretation Algorithms in Support of the

Magnetometer Towed Array by G. P. Malafsky, J. R. McDonald and J. R. Cochran, March 29, 1994. This report contains proprietary information and was not release for general distribution.

7.4 Landfill Characterization and Monitoring System

The Landfill Characterization and Monitoring System (LCMS) was funded by the MWLID Program to create a systems approach for characterizing and monitoring metal and mixed waste contaminants, sources of contamination and contaminant migration beneath landfills. The emphasis of the system is on minimal-intrusive technologies and downhole sensors whenever possible. The system focuses on utilizing the best of available and emerging technologies with minimal developmental work.

The LCMS consists of four separate subsystems: (1) screening technologies; (2) drilling technologies; (3) on-site field lab analysis and (4) in-situ borehole technologies. One of the LCMS's tasks is for Target Validation and Calibration of Unknown Buried Objects discovered using data collected by the MTA and other sensors at TA-2. TA-2 was selected for this task because of the existing MTA, EM-61, EM-31 data as well as data collected from a passive soil gas survey. Additionally, TA-2 contains a great variety of ER sites including a Radioactive Waste Landfill, a Classified Waste landfill, contaminated septic systems, underground storage tanks and a high explosives burn pit.

Utilizing the various non-intrusive information, the focus of the task was to improve, validate and calibrate algorithms and visualization methods used to identify buried objects. NMSU's MAPER software was used to synthesize the various data types, including aerial photography, into an interpretation of the character of buried objects. The MTA responded only to ferrous objects, the EM-61 and EM-31 respond to ferrous and non-ferrous metals and the soil vapor survey responded to volatile and semi-volatile organic vapors. The combination provides a wide variety of targets for analysis and excavation. A number of targets were excavated for calibration purposes, but no landfill targets were excavated for health, safety or waste disposal reasons.

A report documenting the findings is forthcoming; however, there were two very important conclusions. First, a number of the magnetic anomalies were created by natural, metal-bearing (magnetite) channel deposits. As previously discussed, the old roadbed in the back of TA-2 contains magnetic sand. Second, the accurate location of data points is crucial. Successfully overlaying four types of data and trying to analyze targets requires that each data set be correctly located in latitude and longitude. Unfortunately, the various data sets were collected using different standards and reference points. For example, the EM-61 data was collected on a

relative grid, the corners of which were reasonably well established and the interior grid was by tape and eye. The MTA depends on user-supplied coordinates of the base station. The absolute accuracy of the MTA location data is only as good as the coordinates of the base station.

7.5 EM-61 Survey of Radioactive Burial No. 11

As previously discussed, one of the instruments being incorporated into MTADS is a Geonics EM-61 metal detector. To test and contrast the capabilities of the EM-61, a significant portion of the RB-11 Landfill was surveyed on a 1 meter by 0.2 meter grid using an EM-61. The results of this survey are reproduced in the Appendix. Figure 11 is a photograph of the EM-61 surveying the RB-11 Landfill.

7.6 Field Demonstration at Los Alamos National Laboratory

The FY 1994 field demonstration at LANL began in July of 1993 as Sandia staff contacted individuals at several facilities, including LANL. LANL has a number of large landfills and expressed an interest in hosting a MTA survey. Sandia staff traveled to LANL in April of 1994 to visit ER Program candidate sites for the FY 1994 field demonstration and to meet with Nic Jostin and observe the Rapid Geophysical Surveyor (a magnetometer-based technology from the DOE/OTD former Buried Waste Integrated Demonstration Program).

In June of 1994, Sandia and NRL representatives visited LANL and met with LANL representatives to scope the FY 1994 Field Demonstration. A number of candidate sites were visited. Material Disposal Areas (MDAs) associated with TA-21 (MDAs A, B and V) were visited first. MDA A is an old (circa 1945), interesting landfill that has been the subject of extensive and well documented geophysical investigations. MDA V received effluent from the TA-21 laundry and has significant vegetative cover. MDA B is also a 1945 vintage landfill; the eastern third is being used to study natural vegetation on radioactive landfills and the western two-thirds is paved and vacant. Although the TA-21 MDAs were interesting, MDA C was more suited for a field demonstration.

MDA C covers 12 acres and contains 6 large trenches, a chemical disposal pit and 108 disposal shafts. The landfill was used from 1948 to 1974. The trenches are 500 to 700 feet long, 40 to 100 feet wide and about 20 feet deep. The chemical pit is estimated to be 180 feet long, 25 feet wide and 12 feet deep. The disposal shafts are one or two feet in diameter and 15 to 25 feet deep. Due to surficial contamination, 1.5 to three feet of cover was placed over the entire landfill in 1984. The contents of the landfill include vials of radium-226, beryllium chips, urine samples, a plutonium slug, compressed gases, lanthanum-140, strontium-89,

fuel elements (rods), cobalt-60 slugs, uranium (miscellaneous isotopes), yttrium, silver-110, sodium-22, cerium-137, neptunium-237, vacuum-pump oil, fuel element end caps, acetone, zirconium carbide, americium-242, a LAMPRE (plutonium recycle reactor) rod assembly and much, much more.

After the June meeting, we learned that the LANL ER Program was completing a magnetometer survey of a 20 acre landfill at the Los Alamos Airport. The site is open, flat and the conventional survey was being conducted on a ten-foot by twenty-foot grid. The Los Alamos Airport (also known as Solid Waste Management Unit (SWMU) Group 73-1) is composed of four individual SWMU's, two of which are the Debris Disposal Area and the Landfill.

The Landfill was operated by the DOE (and its predecessors) and the county of Los Alamos from 1943 to 1973. The operational history changed over time with the site serving as a burning area/landfill for the majority of its history. Information about the early operations is vague; "a yet to be identified radioactive disposal area in the vicinity of the airport was active in 1943-1944 ... On high oblique aerial photography taken in 1946, large trenches north of the current runway are two possible sites for this disposal area." One of these trenches is near the north edge of the Landfill and the other is on the south edge where the Landfill narrows.

The county of Los Alamos operated this Landfill (i.e., city dump) from about 1965 to 1973. Typical operations involved burning municipal trash and then burying the remaining ash and debris onsite. Much of this debris was apparently buried in a small canyon which cut into the top of the mesa from the north. We estimate that the Landfill may be as much as 75 feet thick at the edge of Pueblo Canyon. The Landfill is approximately 0.5 miles long and 0.1 miles wide, at its widest. After reviewing these sites (MDAs A, B, C, V and the Airport), MDA C and the Airport Landfill were selected for the MTA field demonstration, .

NRL, Geo-Centers, Sandia and LANL undertook a significant effort to complete the Health and Safety Plans, the Site Work Plans, the identification of 1st Order survey control points, radiation and chemical walkovers and the Readiness Review.

Staff again met at LANL in July for the Pre-Survey visit. The actual field demonstration was conducted August 22-25, 1994. A public demonstration of the MTA was provided on August 25, 1994 at the Los Alamos Airport. Figure 12 is a photograph of STI system surveying at the Los Alamos Airport.

Among the highlights of the demonstration was the identification of a number of the one- or two-foot in diameter burial shafts at MDA C. None of these shafts could have been positively identified by a geophysical survey utilizing a conventional five or ten foot grid. Figure 13 is an image from the southwestern corner of MDA C, showing some of the two-foot in diameter burial shafts.

Figure 11 - Photograph of the Geonics EM-61 being used to survey the RB-11 Landfill.
47/48

Figure 12 - Photograph of STI unit surveying at the
Los Alamos Airport, magnetometers raised to 72 inches above the ground.
49/50

Figure 13 - Image from the southwestern corner of Los Alamos MDA C, showing magnetic anomalies created by some of the two foot in diameter burial shafts.

51/52

The largest of the three areas at MDA C, an eight acre area, was surveyed in 95 minutes and hardcopy results of the survey were available the next day. In several areas of the landfill the magnetometers failed to register data. All of these data holidays occurred inside areas registering strong variations in the strength of the magnetic field. After some research, NRL concluded that the combination of sloping terrain and strong anomalies in the magnetic field, drove the magnetic field lines into the dead zone of the cesium vapor sensors, as is discussed in detail in the final report. The final report for the Airport landfill also contains a brief comparison between the MTA and conventional technology.

The reader is urged to read McDonald *et al.*, 1994b, and McDonald and Robertson, 1995 for additional details. These surveys were the culmination of significant efforts by the NRL, Geo-Centers Inc., LANL and Sandia and provide additional evidence of the outstanding utility of the MTA for characterizing DOE buried waste sites.

8.0 FY 1995 Activities

8.1 Introduction

The FY 1995 efforts were to be focused on: (1) integrating (as proof-of-principle) at least one new sensor into the existing platform; (2) demonstrating the new sensor(s) at a test site containing ferrous and nonferrous buried objects; (3) assisting in the technology transfer to field application through formal presentations and an article submitted to a prominent HazWaste journal, and (4) writing a report documenting the field demonstration at Los Alamos.

8.2 Comparison of data from EM-61 and the MTA at RB-11

One of the more important aspects of the MWLID Program was the comparison of the innovative technology to the conventional technology. For the RB-11 Landfill, we had access to the survey results from a conventional, total field magnetometry survey conducted by staking the site and, manually taking individual measurements of the total field on a coarse grid. We also had the MTA high-density data from FY 1993 and the high-density EM-61 data from FY 1994. As part of getting the word out, and demonstrating the innovative technology at real sites, an article was written comparing and contrasting the results from the three surveys. Kim Dalton Linder presented this article at the Symposium on the Application of Geophysics to Engineering and Environmental Problems

(SAGEEP'95) Conference held in Orlando, Florida in April 1995 (Cochran, and Dalton, 1995). The article is also reproduced in the Appendices of this report.

8.3 Field Tests of Multiple Sensors at Ft. Devens

From December 5th through December 7th, 1994, a number of sensors were used by NRL and Geo-Centers to collect data on a high resolution grid using or simulating the MTA tow platform. The surveys were conducted at Ft. Devens which is located about one hour drive from Boston, MA. An existing, geophysics test bed is located in a small field near the center of Ft. Devens. Tests included:

1. Total field magnetometry from seven cesium vapor magnetometers each mounted 18 inches above ground using the STI platform.
2. Total field magnetometry from seven cesium vapor magnetometers each mounted 72 inches above ground using the STI platform.
3. Total field magnetometry with the cesium vapor mags, four mags at 18 inches and four mags at 36 inches, directly above the other four mags for the vertical gradient in the total field.
4. Two EM-61's manually towed by three people, one with the Trimble Navigation System in a pack, and two, each with EM-61 electronics/battery packs, the EM-61's were strapped together with PVC pipe and duct tape, Geonics had modified these EM-61's to fire simultaneously and Geo-Centers had built a trigger to take the 1 Hz Trimble signal and send a 3 Hz trigger to each EM-61.
5. Total field magnetometry from seven cesium vapor magnetometers each mounted 18 inches above ground using the STI platform and a second trailer composed of two EM-61's. (see Figure 14)
6. Seven "matched" Schonstedt's, in seven tubes mounted on the STI trailer.

All three days were rainy and cool. Tests were curtailed early on the afternoon of December 7th, as the temperature was dropping and it was raining hard. A full summary of these tests will be forthcoming in a document from NRL.

8.4 Termination of Funding

The deployment of the commercial MTA in late 1993 raised concerns that DOE/OTD funds were being allocated to a technology that was now commercially available. The FY 1995 proposal to the MWLID Program emphasized the need to "get the word out," to add multiple sensors to the existing platform and to completed the data interpretation work. Just before December 25, 1994, DOE/OTD made the decision to retract remaining FY 1995 funds. A copy of the retraction letter is included in the Appendix.

Figure 14 - Photo of the STI platform with
magnetometers and a second trailer with two Geonics EM-61's.
55/56

Despite the significant advantages of the MTA, and the DOE investment of several hundred thousand dollars, only a few acres of DOE abandoned waste sites were ever commercially surveyed with the MTA, those were the few acres of TA-2 which were surveyed in the fall of 1993.

Parallel to the DOE-funded efforts, NRL had worked to restore funding on the DoD side and in FY 1995, NRL received 1.3 M dollars to continue the MTADS efforts.

9.0 References

- Breiner, S. 1973. Applications Manual for Portable Magnetometers. Sunnyvale, CA: GeoMetrics, Inc.
- Bishop, J. January 1994. "Magnetic views ...," Hazmat World. 21.
- Bremser, J.P. and S.R. Booth. 1993. Cost Effectiveness of the Surface Towed Ordnance Locator System (STOLS). LA-UR-93-4396. Los Alamos, New Mexico: Los Alamos National Laboratory.
- Cochran, J.R., and K.E. Dalton. 1995. "Using High Density Magnetics and Electromagnetic Data for Waste Site Characterization," Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, SAGEEP '95, Conference, April 23 - 26, 1995, Orlando FL. Englewood, CO: Environmental and Engineering Geophysical Society. 117-125.
- Geonics Limited. 1994. EM-61 High Sensitivity Metal Detector Operating Manual, Mississauga, Ontario, Canada: Geonics Limited.
- Environment Today. February 1994. "Magnetic Imaging System Detects Buried Wastes," Vol. 5, No. 2, 48.
- Environmental Remediation Technology. December 1, 1993. "Sandia Uses Navy Ordnance Locator to Find Buried Waste Containers," Vol. 1, No. 6, 53-54.
- Hempen, G.L. and A.W. Hatheway. 1992. Geophysical Methods for Hazardous Waste Site Characterization, Special Publication No. 3. Sudbury, MA: Association of Engineering Geologists.
- Hyndman, D. A. June 1994. EM-61 High Resolution Electromagnetic Survey RB-11 Landfill, Kirtland Air Force Base, Albuquerque New Mexico, Albuquerque, NM: Sunbelt Geophysics. (see Appendix G)
- IT Corporation. March 1988. Results of Site Investigation and Magnetics Survey of the RB-11 Radioactive Burial Site Kirtland Air Force Base, New Mexico, Albuquerque, NM: IT Corporation.
- Linder (Dalton), K.E. 1995. Hybrid Geophysical Inversion for Subsurface Characterization. Dissertation submitted to New Mexico State University. Las Cruces, NM: New Mexico State University.

- MacLean, H.D., J.W. Dickerson, J.C. Hasbrouck, and E.T. Cotter. 1991. "Geophysical Surveys for Underground Storage Tank Locations, Hickman Air Force Base, Hawaii: A Case Study," Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 11-14, 1991, Knoxville TN. Golden, CO: Society of Engineering and Mineral Exploration Geophysicists. 323-341.
- McDonald, J.R., H.H. Nelson, and R. Robertson. 1993. Microwave and Differential GPS Navigation Systems: Field Performance Tests. NRL/PU/6110-93-244. Washington, DC: Naval Research Laboratory.
- McDonald, J.R., R. Robertson, and J.R. Cochran. 1994a. Results of a Magnetometer Towed Array Survey and Sub-System Testing at Site RB-11, Kirtland Air Force Base, Albuquerque NM. NRL/PU/6110-94-257. Washington, DC: Naval Research Laboratory.
- McDonald, J.R., R. Robertson, and J.R. Cochran. 1994b. TA-73, The Airport Landfill, A Magnetometer Towed-Array Survey, Los Alamos National Laboratory, Los Alamos, NM. NRL/PU/6110-95-277. Washington, DC: Naval Research Laboratory.
- McDonald, J.R., and R. Robertson. 1995. Results Of A Magnetometry Survey At TA-50, MDA-C, Los Alamos National Laboratory, Los Alamos, New Mexico. NRL/PU/6110-95-278. Washington, DC: Naval Research Laboratory.
- McMahon, R.F., and R.E. McIntire. October 1966. "Magnetic Anomaly Computations: Magan 360 - Magnetic Anomaly Computations for IBM System 360," Exploratory Geophysics. Denver, CO: Chevron Oil Company. Western Division.
- Naval Explosive Ordnance Disposal Technology Center. September, 1991. UNDEX Site Survey Report, Combat Systems Test Activity, Aberdeen Proving Grounds, MD. Indian Head MD: Naval Explosive Ordnance Disposal Technology Center.
- Naval Research Laboratory. 1992. Magnetometry & Radar Evaluation of Toxic and Hazardous Waste Sites at the Sandia National Laboratory, NRL Pub. No. 61-M213-X-1. Washington, DC: Naval Research Laboratory.
- SAIC (Science Applications International Corporation). 1985. Installation Restoration Program, Phase II - Confirmation/Quantification, Stage 1, Kirtland AFB, New Mexico, prepared for USAF, Headquarters Military Air Lift Command (HQ MAC/SGPB), Scott AFB, Illinois and USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas. SAIC 2-827-06-351-

33. Albuquerque, NM: SAIC.

Sandia Science News. February 1994. "Magnetic survey system adapted for hazardous waste sites," Vol. 29, No. 2, 3.

Sandia Technology, Engineering and Science Accomplishments. February 1994. "Toxic Waste," Albuquerque NM: Sandia National Laboratories. 34-35.

Skinner, L. Technology Transfer Business. Winter 1995. "Going Green," Vol. 3, No. 2, 19-26.

10.0 Appendices

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Appendix A FY 1993 Monthly Highlights

11/1992

- \$350 K made available December 1992, no activity to date.

1/1993

- The Technical Task Plan (TTP) was rewritten to incorporate DOE and Sandia reviewers comments and to match the provided FY 1993 funds. Meetings were held in Albuquerque on January 13, 14 & 15 between Sandia, the NRL, Geo-Centers Inc., New Mexico State University Mechanical Engineering and MWLID staff. Significant among the accomplishments were: a "meeting of the faces"; refinement of the FY 1993 goals; scoping of the FY 1994 proposal, and a site tour of the RB-11 landfill.
- Procurement request initiated to transfer \$140 K to Geo-Centers and \$155 K to NRL.
- Geo-Centers has decided to commercialize the magnetometer towed array and is currently constructing their first commercial unit; the first demonstration of the first commercial unit will be at MWLID's RB-11 landfill.
- NRL has setup the "test track" for testing navigation systems and has invited all major manufacturers of navigation systems for a shoot-out in February.
- Sandia is gathering necessary background information to support the field demonstration at RB-11 in September.

2/1993

- The navigation system test track was setup at the NRL Chesapeake Beach Detachment, Chesapeake Beach, MD.
 - Field evaluations began the week of February 15, 1993
 - A total of eight vendors have agreed to demonstrate their navigation systems.
 - Three of the vendors demonstrated GPS systems and four of the vendors demonstrated beacon based microwave systems; a fourth vender (Ashtec) will provide a demonstration in early March.
 - At least one of the GPS vendors demonstrated the ability to provide x,y locations at 1 Hz at +/- 0.5 meter on a vehicle moving at 3 mph.
- Geo-Centers continues work on their commercial version of STOLS.

- The navigation software being written to accept either microwave or GPS input because not sure which type of system will be deployed at RB-11.

3/1993

- A Statement Of Work to begin the development of better data interpretation algorithms was completed.
- The FY 94 TTP for continued funding of this project was completed and submitted.
- Contact was made with the Jerry Sandness (TTP No. RL313203) who is involved in the program to development a remotely deployed vehicle which can carry two magnetometers.
- The ProTech Profile was completed and submitted.

4/1993

- An additional \$50 K in capital funds was received in April. However, operating funds and not capital funds are needed. The \$50 K has been returned to DOE/HQ to be exchanged for \$50 K in operating funds.
- The report documenting the performance of the eight navigation systems which vendors demonstrated has been drafted and distributed to vendors for review. Basically, vendors demonstrated their ability to locate targets on a test track while driving through the test track at 5 + mph. Some vendors demonstrated real time 100% accuracy at ≤ 1 meter error, and 100% accuracy at ≤ 0.5 M error in post processing. Other vendors were less than 10% accurate.
- A presurvey of the RB-11 landfill was conducted on 4/26 by a NRL representative using a handheld magnetometer, numerous metallic targets were located in each trench, although no trench is completely full of metallic targets.

5/93

- A Trimble Navigation 4000 SSE dynamic GPS system with the associated support equipment has been purchased and is being integrated into towed array. The Ashtech GPS performed as well as the Trimble, the Trimble was chosen because they were able to deliver their equipment 6 weeks earlier than Ashtech (which is important for a 9/30/93 demonstration).
- A presurvey of the RB-11 landfill was conducted on May 5 - 7 by a Geo-Centers, NRL and two vendors using dynamic GPS (Trimble) and microwave based (Sercel)

navigation equipment. Based on draft data, both navigation systems functioned well at the RB-11 landfill.

6/1993

- A meeting was held with MWLID staff to have the clutter (telephone poles, concrete blocks, portable buildings ...) removed from the surface of the RB-11 landfill.
- Work continues on proposals for solving the magnetic anomaly "extended target" problem.

7/1993

- September 7 - 9, 1993 has been selected as the date for the field demonstration of the towed array at the RB-11 Landfill.
- Sandia personnel are working with LANL for a possible FY 94 field demonstration of the towed array at LANL.
- Geo-Centers staff is working with MWLID staff to develop a Health and Safety Plan for the September field demonstration.
- The first field test of the Geo-Centers commercial towed array was conducted at Ft. Devens on July 28; though there were some problems, the overall test was very successful.
- Proposals were solicited for burying calibration targets near RB-11. The calibration targets will probably consist of some combination of 55 gallon drums and a large steel plate.
- Data collected during the navigation system presurvey of the RB-11 landfill has been analyzed; there are no Sandia specific interferences with either microwave or GPS based navigation systems.

8/1993

- MWLID (Bob Floran) will fund the burial of Calibration Targets.
- Geo-Centers staff has completed a Health and Safety Plan for the September field demonstration.
- NRL developing Test Plan for activities at RB-11.

- Field tests of the Geo-Centers commercial towed array have been successful (including the integration of the Trimble GPS !).
- The configuration of the Calibration Targets has been defined and will consist of 5 burials, one steel plate and four configurations with 55 gallon drums.

9/1993

- All FY 1993 Milestones were met:
 - The Field Demonstration was conducted on schedule; September 7 - 9, 1993.
 - The report detailing the navigation system "shoot-out" was distributed on 9/23/93.
- The Field Demonstration was very successfully completed, 9/7 through 9/9:
 - Field demonstration began on 9/7 with a rad. screening of towed array and Health and Safety Briefing.
 - Less than 2 hours was required to actually survey RB-11 on 9/7
 - Previously unidentified, large (1" diameter) electrical cables were found to be buried across some of the pits at a depth of about 3 feet.
 - The collapsing trench was found to contain almost no metal.
 - On 9/8 additional surveys were conducted at RB-11
 - On 9/9 the Calibration Targets were surveyed with both STOLS and hand held equipment

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Appendix B FY 1994 Monthly Highlights

10/1993

- NRL is working on the RB-11 Survey Report.
- Sandia continues to work on a "NEWS RELEASE"
- \$17 K transmitted to NMSU for work on the extended target problem.

11/1993

- A Sandia NEWS RELEASE was completed on 11/8/93 and transmitted by Sandia Public Relations to a preexisting mailing list of agencies and publications.
- A STOLS poster was exhibited by Geo-Centers at the DOE Technology Information Exchange Workshop in Denver.
- Sandia visited NMSU on 11/18 to review their work on the extended target problem.
- Proposals received from ARC, New Mexico State Univ. and Geo-Centers for conceptual approach to solving extended target problem.

12/1993

- A draft cost-benefit analysis of the MTA technology was completed in mid-December. The report was not transmitted to the PI (Cochran) however Geo-Centers Inc. received a copy prior to Christmas. The reports authors and Geo-Centers traded letters over the Holidays and efforts will continue in January to reach an acceptable compromise.
- Cochran attended and made presentation at "Principal Investigators FY94 Kickoff Meeting", Albuquerque December 13 & 14, 1993

1/1994

- A draft cost-benefit analysis of the MTA technology was completed by LANL in mid-December. The report has undergone significant written review and a meeting was held in Albuquerque on 1/21/94 to resolve a number of outstanding issues. Overall interactions have consumed a significant amount of (unbudgeted) time and energy.
- Full budget authority was received in late January
- Full budget authority of \$460 K in FY94 funds received 1/6/94 plus authorization

of the \$55 K carryover was received 1/31/94.

2/1994

- Two locations at Los Alamos have been tentatively identified for the FY 1994 field demonstrations.
- The Procurement Request to transfer FY 1994 funds to the Navy and Geo-Centers is deep in the Sandia financial system.

3/1994

- "Review and Selection of Proposals to Develop Data Interpretation Algorithms in Support of the Magnetometer Towed Array." was completed and transmitted in late March.
- "Results of a Magnetometer Towed Array Survey and Sub-System Testing at Site RB-11 Kirtland Air Force Base, Albuquerque, NM." was transmitted in late-March.
- The Procurement Request to transfer FY 1994 funds to the Navy and Geo-Centers has been completed.
- In late-Feb/early-Mar a poster on the Magnetometer Towed Array was included in the Sandia booth at Waste Management 94 in Tucson (the largest waste management conference in the country with over 2,200 attendees).
- A four day "DOE/EM Commercialization Planning Workshop" was attended and a draft commercialization plan was completed.
- Letter Report, Evaluation of Proposals for Extended Target Analysis mailed 3/29/94.

4/1994

- Sandia staff traveled to Los Alamos Lab on April 28. The trip had two purposes. First, to visit LANL ER Program sites which are candidates for the FY 94 field demonstration of the MTA and second to meet with Nic Jostin and observe the Rapid Geophysical Surveyor (a magnetometer-based technology from the BWID program). For the FY 94 field demonstration, a number of Material Disposal Areas (MDAs) were visited including some which have had prior, conventional geophysics and some which have had no prior geophysics. Observed the Rapid Geophysical Surveyor surveying a 2 acre, "treed" site and we discussed many topics of common interest.

5/1994

- Sandia and NMSU staff met in Las Cruces on May 19 to discuss the mathematical and software work Dr. Hensel will be doing to help solve the extended target problem. Dr. Hensel and his students will implement the first two steps of their three step proposal to solve the extended target problem.

6/1994

- For the DOE OTD Technology Catalogue, several iterations of draft text were completed.
- Also, draft text was reviewed for the ProTech Technology Information Profile.
- On June 15, sections of the RB-11 Landfill were surveyed with an EM-61. The EM-61 is being considered as one instrument that might be deployed on the towed array platform. Sandia and NRL staff observed some of the survey and met with the contractor (Sunbelt Geophysics) to discuss the strengths and weaknesses of the EM-61.
- On June 16, Sandia and NRL representatives traveled to Los Alamos and met with LANL staff.
- Vuegraphs providing an overview of the MTA technology were mailed to sponsors and a number of interested parties on June 17
- Significant efforts have been dedicated to setting up the field demonstration at LANL (e.g., Health and Safety protocol, site maps, site histories, land survey benchmarks, ...)
- After much time and effort, the contract with NMSU was signed on June 22 (one month into the three month contract).

8/1994

- Two large landfills at LANL were surveyed using the MTA. This August 22-25, 1994 field demonstration provided yet another example of the significant advantages of the high density data provided by the MTA.
- Researchers from NMSU and Sandia met on 8/3 to discuss progress to date on (1) developing algorithms for extended targets and (2) work on the Landfill Characterization and Monitoring System. The visit included a tour of the TA-2 sites included in the analysis. The NMSU work is progressing well, although a significant amount of time was required to convert the various digital data sets

(e.g., aerial photos, magnetometer towed array, EM and topography) into a common coordinate system. The NMSU meeting included significant involvement with the EM-40 task leader (Rarilee Conway).

- Approximately twelve NMSU students are employed by this task.

9/1994

- The Sandia LCMS project is excavating several targets in TA-2. Targets for excavation were identified by NMSU using data from the MTA, an EM-31, an EM-61 and soil vapor analysis. Significant problems have been encountered in location targets in the field. Sandia contractors may have used a 1927 surveying reference system to establish the known survey locations against which the data was collected.
- The TTP was rewritten for FY95 funding. Adding a new sensor the existing platform and technology transfer are the areas emphasized.
- The Commercialization Plan was finalized

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Appendix C FY 1995 Monthly Highlights

11/1994

- The close-out meeting for the FY94 NMSU activities was held in Las Cruces on November 4. Work related to the LCMS, TA-2 data analysis and the development of algorithms for the analysis of extended magnetic targets was discussed. A report containing a discussion of the activities was distributed.
- The report on the cost-effectiveness of the Magnetometer Towed Array was released. This report (LA-UR-93-4396) was written by LANL with DOE/OTD funding.
- NRL continued analysis of the data collected during the FY94 Field Demonstration at Los Alamos.

12/1994

- The NRL and Geo-Centers Inc. demonstrated a number of new sensors the week of 12/5/94. These sensors were demonstrated at an existing cold test area at Ft. Devens (an hour NW of Boston) during a cool and rainy week. Results from these tests will be reported by the Navy prior to the end of the FY.
- An abstract has been accepted for presentation at the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP). The paper by Kim Dalton Linder (NMSU) and Cochran discusses work at RB-11 Landfill.
- An abstract has been accepted for presentation at Waste Management '95 in Tucson.
- An abstract on MAPER was presented at the 1994 AGU Meeting in San Francisco
- A small contract with a local geophysics company has been let, this company (Sunbelt Geophysics) is very experienced with the EM61 and will add expertise to the interpretation of EM61 and mag. data.
- A new contract is being negotiated with New Mexico State University, like the FY94 contract, the emphasis will be on the interpretation of mag. data, almost all the funds are for employment of PhD candidates.

1/1995

- The report on the FY94 Field Demonstration at the Los Alamos Airport Landfill has been reviewed internally and corrections are being made. The report on the

survey of the Los Alamos Landfill C is in internal review.

- The paper title "Using High-Density Magnetic and Electromagnetic Data for Waste Site Characterization, A Case Study" was completed for the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP).
- The FY 1995 budget was reduced to \$20 K (the approximate spending to date); approximately \$15 K in carryover from FY 1994 remains.
- A letter detailing the budget cut was mailed to team members.
- The paper for presentation at Waste Management '95 was canceled due to the budget cut.
- The report on other types of sensors which could be incorporated into the existing system has been canceled due to the budget cut.
- A contract New Mexico State University was signed in January, however the contract will not be funded due to the budget cut.

2/1995

- The NRL has been funded \$1.3 m in FY95 for further development of the Multi-sensor Towed Array Detection System (MTADS), the next generation of the MTA.

4/1995

- Kim Dalton (NMSU) presented the paper titled "Using High-Density Magnetic and Electromagnetic Data for Waste Site Characterization, A Case Study" at the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP).

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Appendix D Funding Summary

The original STOLS was jointly developed by the Navy Explosives Ordnance Disposal Technology Center and the NRL, with sponsorship from the Army Corps of Engineers. Primary R&D support was provided by Geo-Centers Inc. of Boston, MA.

In late 1991 this system was used to characterize several buried waste sites at Sandia National Laboratories (utilizing DOE/EM-40 funds). Shortcomings were recognized and DOE/OTD funds were sought to improve the system for DOE hazardous waste site characterization needs. Independently and prior to DOE/OTD funding, Geo-Centers decided to commercialize the technology.

During FY's 1993, 1994 and 1995 the STOLS concept was refined utilizing three funding sources: Geo-Centers commercialization funds; Strategic Environmental Research and Development Program (SERDP) funds administered through the Naval Facilities Command and the OPNAV-045 Shoreside Environmental RDT&E Program and DOE/OTD funding administered through the MWLID Program. The following section summarizes the DOE funding profile for the MTA.

FY 93 Budget

- In
- \$350 K authorized 12/92
 - \$50 K additional capital funds authorized 4/93 and converted to operating funds on 9/21/93

Allocation by organization

- \$ 155 K to NRL
- \$ 140 K to Geo-Centers
- \$ 50 K Sandia (\$30 K to taxes)

Allocation by task

- \$ 130 K select and purchase GPS System
- \$ 50 K Data Interpretation
- \$ 115 K Demonstrate MTA at RB-11
- \$ 50 K Sandia support and taxes
- \$ 55 K carry over (\$ 50 K received with 9 days left in FY 93)

FY 94 Budget

- In - \$ 460 K authorized 1/94
 - \$ 55 K carry over

Allocation by organization

- \$179 K to NRL
- \$132 K to Geo-Centers
- \$131 K Sandia (\$35 K to taxes)
- \$ 39 K NMSU
- \$ 4 K Sunbelt Geophysics

Allocation by task

- \$ 12 K DOE/HQ funding pull-back of 3/93
- \$ 76 K write RB-11 Report
- \$ 89 K Data Interpretation
- \$165 K Demonstrate at LANL
- \$ 20 K MTADS Report (never completed)
- \$131 K Sandia support and taxes
- \$ 18 K carry over
- \$ 4 K EM-61 Survey at RB-11

FY 95 Budget

- In - \$107 scheduled, but \$ 20 K authorized 12//94
 - \$ 18 K carry over

Allocation by organization

- \$ 38 K Sandia

Allocation by task

- \$ 38 K "getting the word out"

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Appendix E Sandia Memos on LANL Cost Study

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: January 13, 1994

to: John Bremser, LANL, MS B299

from: John Cochran, MS 1345, org. 6331

subject: Comments on "Cost-Effectiveness of the Surface Towed
Ordinance Locator System (STOLS), draft of January 11, 1994

This version is much better than the November 30, 1993, version and clearly reflects some of the continuing dialogue between us. However, several key issues must be addressed to make this report defensible.

One variable that requires additional research concerns the size of a typical DOE site. The current Abstract is very blunt in stating that "...STOLS is not a cost-effective system to use at this time..." because the typical DOE site is 10 acres in size and STOLS is not cost-effective for a 10 acre site.

First, DOE sites are typically addressed in groups; the total acreage being assessed at one time is much larger than the size of an individual site. For example, Sandia's ER Program is addressing over 200 sites, which are grouped together in about 15 management modules (activity data sheets). LANL has over 1,000 sites which are also grouped together in a small number of management modules.

Second, a large number of DOE sites are individually larger than 20 acres. I've attached two memos of January 12, 1994, from the Sandia ER Program concerning site sizes. Similar lists could be obtained from other DOE facilities. The concept of a typical 10 acre site and the link to the statement that STOLS "...is not cost-effective..." should be removed from the report or additional research needs to be conducted.

Further, the statement that "...STOLS is not a cost-effective system to use at this time..." confuses cost per acre and cost-benefit (apples and oranges concepts).

The analysis must also be refined to reflect the costing of conventional surveys. Let's say that GLUEemTOGETHER has developed a better way to

repair transmissions and I would like to assess their claim. I would solicit price quotes from GLUEemTOGETHER, and, for similar repairs, I would solicit price quotes from AAMCO and other transmission repair companies; I would not use a Sears tool catalog to price transmission repair tools and make the comparison via my own estimate. Lets define the cost of conventional services by soliciting price quotes from several geophysical companies throughout the country; these folks (by definition) set the cost of a conventional survey.

Additionally, the current approach tries too hard to display the comparison in black and white; the world simply isn't that simple. The statement that "...the results of the comparison are somewhat mixed..." should not be hidden in the back of the report, this is exactly the conclusion I would expect in the Abstract. The reader should be presented with the variables along with the pros and cons of each. For assessment work, the choice and use of geophysical instruments is site and objective dependent; statements such as "... 5 foot centers are the likely maximum resolution required." are simply incorrect.

Now for the apples and oranges issue. The key question is "what is the customers (DOE/HQ/EM-50) charter for this analysis". There are two paths which can be taken to finalize this report. The first path best utilizes the existing report and minimizes the amount of additional research. Since this draft focuses on cost per acre, the title could be changed to "Cost Per Acre Comparison Between Hand Held Magnetometer Surveys and STOLS". With a little more research towards defining the range of costs associated with conventional surveys and some strong caveats about the other factors important in selecting and using magnetometers, the report could be finalized in short order.

If the charter of this analysis is broader (i.e., a cost-benefit analysis) then quite a bit of additional research needs to be conducted and the report will require a major rework.

I've not done a detailed review of this draft. After the above issues are clarified and the report is revised, I'll be happy to help with the line by line editing.

In summary, we are getting closer to a defensible analysis, however, several key issues need resolution. Questions should be directed to me at (505) 848-0415.

JRC:6331:jrc:Cost Effect Analysis 1/94

Attachments (2)

cc (w/attachments):

Jim McDonald

Naval Research Laboratory, Code 6110

Washington DC 20375-5000

Dick Russell

GeoCenters Inc.

7 Wells Ave.

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MS 1345 D. Gallegos (6331)

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MS 1345 Day File (6331)

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: March 11, 1994

to: John Bremser, LANL, MS B299

from: John Cochran, MS 1345, org. 6331

subject: Comments on "Cost-Effectiveness of the Surface Towed
Ordinance Locator System (STOLS), draft of March 1, 1994

This draft is very readable and opens with an even-handed tone which is greatly appreciated. The addition of the Survey of Contractor prices also adds credibility to the report (although the report fails to make any use of the data).

The following comments are offered as "polish" and, in some cases, to correct technical inaccuracies.

pg 1 par 3 - I still find little evidence to support the assertion that 50 acres is "very large" because:

(1) Appendix D of this draft was constructed from information provided by the Sandia ER Program, however Sandia's largest site (Antelope Lake at 2,000 acres), Sandia's second largest site (Clean Slates 3 at 550 acres), etc. were not included in Appendix D, please refer to my memo of January 13, 1994 for the remainder of the "missing" sites - the addition of these missing sites more than doubles the size of an average site

(2) as discussed in my memo of January 13, 1994 "DOE sites are typically addressed in groups; the total acreage being assessed at one time is much larger than the size of an individual site. For example, Sandia's ER Program is addressing over 200 sites, which are grouped together in about 15 management modules (activity data sheets). LANL has over 1,000 sites which are also grouped together in a small number of management modules."

pg 1 par 3 - suggested rewrite "STOLS does not become clearly cost-

effective ... until the *total area surveyed* reaches 50 acres ~~survey site a very large size (i.e.,)~~."

pg 1 par 3 - let's use the actual definition of "typical site" which is "a site consisting of rolling terrain with some natural and cultural interferences where STOLS survey rates are about 12 acres per day" rather than the current definition which has a negative tone and fails to communicate

pg 1 par 3 - suggested rewrite "In this report, by "typical site" we mean simply *a site consisting of rolling terrain with some natural and cultural interferences where STOLS survey rates are about 12 acres per day* ~~that the site does not conform to the conditions of a site that is ideally suited for the use of STOLS as outlined in Section 5.2 of this report.~~"

pg 2 par 2 - suggested rewrite "However, when high resolution is required *and/or when same day turnaround is important and/or* when more restrictive personnel rules are present, ..."

pg 5 par 3 - suggested rewrite "STOLS is a very high density (100,000 data points/acre @ 3.5 MPH) geophysical survey ... "

pg 8 par 3 - same comment as pa 1 par 3 with respect to the definition of "typical site"

pg 13 par 2 - suggested rewrite "Since the STOLS system *uses the same type of magnetometers as are available for a conventional hand-held survey* ~~gives information similar to that which can be obtained using hand-held magnetometer~~ the hand-held magnetometer survey system is used as the baseline technology in this study."

pg 14 Table 4.1 - Grading is not required for a Towed Array Survey (your discussion of site preparation in Section 7 is correct on this point)

pg 17 par 3 - suggested rewrite "... in the absence of any ~~overhead or~~ profits charged by contractors ... " overhead applies to both contractors and in house labor

pg 20 Table 5.1 - "Preliminary Report Preparation Total" should be a "site size dependent variable"

☛ one hour per acre for "data analysis and report preparation" is very unrealistic, as a rule of thumb, 8 hours in the office for every 8

hours in the field - this one for one assumption is verified in commercial cost estimates (e.g., bottom of your Table 5.2.5.1), and the last paragraph of your Appendix B recommends 3 to 4 hours per 8 hours in the field

pg 21 par 4 - in Table 5.1 the "site size dependent costs" are defined in both man-hours per day and in dollars per day, but I'm not sure that both of these costs are carried into the final equation

pg 22 par 1 - same comment as above with respect to data analysis and report preparation costs

pg 23 par 1 - terrain considerations are an important consideration in this analysis; they form the basis for the definition of "typical site" and also enter into the calculation of cost per acre for a STOLS survey

pg 30 par 4 - please remind the reader that your terms "not ideal" and "typical site" refer to rolling terrain where STOLS survey rates are assumed to be 12.5 acres/day and that "ideally suited" refers to open level terrain where STOLS survey rates are assumed to be 30 acres per day (this is a very important point which doesn't seem to be identified in the text)

pg 37 par 1 - suggested rewrite "... 5 ft. centers or larger until *the total area surveyed exceeds 50 acres* ~~a very large site size~~ and a high labor rate are used."

pg 37 par 1 - suggested rewrite "If the site contains only buried waste trenches, *and the only goal of the survey is to identify those trenches*, then a 5 ft. survey (or an even greater grid spacing) ..."

pg 37 par 1 - suggested rewrite "However, surveys performed at sites that contain ill-defined burials *or at sites where characterization is important, or at sites where same day turnaround is important* ~~locations or contain scattered small objects (of the size of a basketball or smaller) buried near the surface~~ would benefit from the added information available when employing STOLS."

pg 52 par 3 - recheck the accuracy of non-differentially corrected GPS

pg 52 par 3 - recheck the accuracy of the discussion of the principle behind differentially corrected GPS

pg 57 par 3 - the implication that level A protection is required at radioactively contaminated sites is not correct, please clarify

pg 69 - as an overview comment, this section makes a number of recommendations beyond the scope of the supporting evidence - most importantly, the scope of this report is cost per acre and the authors have never researched the question of the added value of higher data density, the only exception is a single landfill based on copies of two very small scale plates (which demonstrate the importance of the added data density!!) - therefore, there is no justification in drawing such conclusions as "... we believe that the need for the greater resolution provided by STOLS is not justified by the added cost..."

pg 69 par 1 - suggested rewrite - "Generally speaking, we believe that the DOE sites at which STOLS might be used *are sites consisting of rolling terrain with some natural and cultural interferences, with an average size of 20 acres, requiring level D personnel protection.* ~~fall into the category of non-ideal for STOLS ...~~ Further we believe that the primary purpose of a magnetometer survey is to *located fairly well defined trenches and that same day turnaround is not critical.* Therefore if we consider only these factors, STOLS is not cost effective (Figures 5.7 and 5.9) ~~except where very detailed surveys are required.~~"

pg 69 par 2 - suggested rewrite - "Furthermore, the studies done at Sandia National Laboratories ... by a conventional survey, ~~even a conventional survey using a 2 foot grid.~~"

pg 69 par 2 - suggested rewrite - "For example, in the survey done at Sandia National Laboratories a conventional survey *on 10 foot centers* missed ..."

pg 69 par 3 - suggested rewrite - "In (13), the grid size used for the magnetic ~~gradiometer~~ survey was 10 ~~5~~ feet by 10 feet."

pg 69 par 3 - suggested rewrite - "... but was not sufficient to determine any of the properties of the individual burials *or identify the presence of the buried electrical cables.*"

pg 70 par 3 - suggested rewrite "Thus, the additional data that STOLS provides is of little practical use, *if the original objective is only to located large buried objects.*"

pg 70 par 3 - suggested rewrite "... the conventional method *may* yield acceptable results."

pg 70 - again, you've research one topic (cost per acre) and are drawing conclusion about another topic (average need for high density surveys)

pg 71 par 1 - suggested rewrite "... about 12 acres per day can be surveyed *and for ideal sites the survey rate exceeds 30 acres per day.*"

pg 71 par 4 - suggested rewrite "... namely a ~~non-ideal~~ site *consisting of rolling terrain with some natural and cultural interferences.*"

pg 71 par 4 - suggested rewrite "... and/or *at least 50 acres are surveyed* ~~very large site sizes are present.~~"

pg 72 par 1 - "... is meant to be used only as an aid in the decision process, ~~not as the determining factor as to whether or not to use STOLS.~~" - lets be honest, every other step in the decision tree is use/don't use STOLS

pg 91 - for this decision tree to be useful, such terms as "ideal", "not ideal" and "sufficient" must be defined - in my opinion, the value of this decision tree doe not overcome potential liabilities

Appendix A and B - these are well written guides and reflect current thinking - however, in a few short years this guide will have to be rewritten to reflect the added value of high density surveys (such as STOLS or Appendix C)

Appendix C - recheck the price on your Trimble differential GPS equipment, for the accuracy needed, we invested over \$100,000 in Trimble equipment

Appendix C - I agree with the underlying idea, high density surveys will probably permeate the entire geophysics industry someday (not just magnetometer surveys) - I hope that Geo-Centers is rewarded for being on the leading edge of this trend and receives a fair return on their investment

In summary, I hope that these comments help make the report more defensible. Questions should be directed to me at (505) 848-0415.

Bremser

--

March 11, 1994

JRC:6331:jrc:Cost Effect Analysis 3/94

cc:

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Appendix F Administrative Activities

Principal Investigator Kickoff Meeting
Technical Support Group Meeting
Yearend Review
Commercialization Workshop
Monthly Reports
interactions with Sandia Procurement
Cost-Effectiveness Interactions with LANL
Public Relations interface
ProTech Profile
Technical Task Plan budget adjustments
preparation of next years TTP
coordination of above with Navy and Geo-Centers Inc.

Appendix G EM-61 Survey at RB-11 Report

**EM-61 High Resolution Electromagnetic Survey
RB-11 Landfill, Kirtland Air Force Base
Albuquerque, New Mexico**

Prepared for:

**Mr. John Cochran
Organization 6331
Sandia National Laboratories
Albuquerque, NM**

David A. Hyndman

June 1994

Introduction

Geonics Ltd. of Mississauga, Ontario, has recently introduced the EM-61 high precision metal detector into the geophysical instrument market. The EM-61 is a time domain electromagnetic (TDEM) instrument specifically designed for mapping buried metallic objects. Although TDEM is a well known and proven geophysical method for mineral and ground water exploration, the EM-61 is the first commercial application for high resolution, quantitative, buried metal detection.

Organization 6331 of the Sandia National Laboratories (SNL) hired Sunbelt Geophysics of Albuquerque, NM, to perform a high resolution survey (1 m X .2 m) with the EM-61. The primary purpose of the survey was to gather data for a comparison to high resolution magnetic surveying methods. Approximately 0.9 acres of the RB-11 landfill, located on Kirtland Air Force Base, Albuquerque, NM, was chosen for the survey.

Operating Principles

The EM-61 generates electromagnetic (EM) pulses by passing a current through a one meter square coil. These pulses penetrate the subsurface and briefly induce secondary EM fields. Soil has relatively low conductivity and the secondary fields rapidly dissipate. Buried metallic objects have essentially infinite conductivity when compared to soil, and the secondary fields persist much longer. The EM-61 measures the strength of the secondary fields during the "off time" between the primary pulses. The measurement is delayed until the response from the soil has dissipated and only the response of buried metal is present.

The secondary EM fields are measured by a one meter square main sensor which is coincident with the transmitter coil, and by a second one meter square focussing coil positioned 40 cm above the main coil. Each sensor coil measures the secondary field strength during a time gate in between the primary pulses. Two sensor coils are used to allow discrimination of shallow objects from deeper objects. The technical specifications of the EM-61 operation can be found in the Geonics Ltd. literature attached as Appendix 1.

The EM-61 is usually deployed in a trailer configuration pulled by an operator. A "tic wheel" triggers data acquisition by a data logger at intervals of approximately 20 cm. Typical surveying methodology involves acquiring data along parallel traverses covering the area of interest. These parallel traverses can be separated by a few meters when seeking large buried objects. For higher resolution work, the traverses can be positioned closer. Traverses separated by one meter will give complete coil coverage. Overlapping coil coverage can be used if higher lateral resolution is desired.

The anticipated response from standard targets (steel pipes, aluminum pipes, steel balls, aluminum balls, steel drum) as a function of depth are given in the Geonics Ltd. literature in Appendix 1. These figures are useful for predictions, but lack rigorous empirical verification.

Survey Design

An area covering approximately 0.9 acres in the southwest corner of RB-11 was chosen for the EM-61 survey. The location and history of the RB-11 landfill, as well as the previous high resolution magnetic survey are described in McDonald, J.R., Robertson, R., and Cochran, J.R., Results of a Magnetometer Towed Array Survey and Sub-System Testing at Site RB-11, Kirtland Air Force Base, Albuquerque NM. Naval Research Laboratory, NRL/PU/6110-94-257, May 9, 1994. The location of the survey area was determined with respect to four landmark locations (RB-11 #7, RB-11 #1, RB-11 #2, RB-11, #3) previously established for the high resolution magnetic survey. An 75 meter long, east-west baseline was placed a few meters south of RB-11 #2. A parallel endline was established 50 meters to the north (see attached map for survey area details). Alternating color pin flags were placed every one meter along the baseline and endline, marking parallel traverses separated by one meter. The instrument was pulled from the baseline to the endline, with data acquisition controlled by an Omnidata Series 600 data logger.

Processing

The EM-61 data were transferred from the data logger to a personal computer for processing and plotting. The DAT61 program (Geonics Ltd.) was used for basic data reduction. The Geosoft Mapping and Processing System (Geosoft Inc.) was used for data processing and imaging.

The desire to demonstrate the basic capabilities of the EM-61 dictated that no heroic efforts be made to enhance the data through processing. A noise level of approximately 1.5 mV (positive and negative) was observed. 2 mV was added to the main and focussing coil measurements in order to shift the noise to a positive value. A minimum of 5 mV was chosen for the color presentation and contouring to insure representation of the data above the noise. Other than the filtering intrinsic to creating a gridded image from discrete data, no other changes were made to the field measurements.

The focussing coil measurement allows some discrimination of shallow from deeper buried metal. One method suggested by Geonics Ltd. is to simply subtract the main coil measurement from the focussing coil measurement. The resulting difference data will display negative values for surface or very shallow objects. This approach was followed and an image was generated for only the positive values.

Results

The results from the EM-61 survey are shown in the following figures. The main and focussing coil data were contoured with dashed lines at 5, 10, and 15 mV, and solid lines at 100, 200, 300, 400, and 500 mV. The difference data were contoured at 0, 5, and 10 mV with dashed lines, and at 50, 100, 150, 200, and 250 mV with solid lines.

The EM-61 images are presented at a scale of 1:1200 (1"=100') for direct comparison to the high resolution magnetic survey data in the previously cited report, and at 1:400 (1"=33.3') for more detailed examination.

Figure 3 - EM61 Survey, 1.0 x 0.2 m. grid (focussing - main), see text for details
103/104

Appendix H MTA, Conventional and EM-61 Comparison

USING HIGH-DENSITY MAGNETIC AND ELECTROMAGNETIC DATA FOR WASTE SITE CHARACTERIZATION A CASE STUDY

**John R. Cochran,
Sandia National Laboratories**

**Kim E. Dalton
New Mexico State University**

INTRODUCTION

Magnetometers are frequently used to characterize hazardous waste sites. Due to cost and time considerations, data are typically collected on a coarse grid with nodes on 3 to 6 meter (m) centers. Hardware and software are now available which allow the rapid and cost effective collection of information on a much finer sampling grid. In this paper we present and compare total field magnetometry data collected on 3 m centers to total field magnetometry data collected on a grid with centers of 0.5 m or less. We also compare the magnetometry data to time-domain electromagnetic (EM) data collected on a 1 m by 0.2 m grid using the recently introduced Geonics Ltd. EM61 metal detector. All three data sets were collected at an abandoned landfill.

WASTE SITE HISTORY

Radioactive Burial Site No. 11 (RB-11) is located on Kirtland Air Force Base near Albuquerque, New Mexico. This 1 hectare (2.5 acre) landfill was used from 1960 to 1971 and is described as containing nine trenches (Installation Restoration Program ..., 1985). Roughly, these trenches are oriented east-west and are believed to range in depth from 2.5 to 6 m, with 1 m of cover. No accurate disposal records were kept. The landfill was used primarily for the disposal of contaminated animal carcasses, animal excreta, and associated laboratory wastes. These wastes contain small quantities of hazardous and radioactive materials. Much of the waste is believed to have been contained in 55 gallon steel drums. The landfill was unmonitored and probably received other types of wastes. An unsubstantiated story reports the burial of a 55 gallon drum of contaminated mercury from the Nevada Test Site (Installation Restoration Program ..., 1985). If the drum exists and it is full, this drum weighs two tons.

WASTE SITE SETTING

RB-11 is situated on the Sandia-Manzano piedmont plain and is relatively flat. The soils are grass-covered and composed of sandy silt and silty sand. The depth to the water table is approximately 150 m. The two southernmost trenches have narrow asphalt caps and one trench in the middle of site has subsided as much as three feet. The edge of a single drum is exposed near the southern end of the site. There are no fences or known utilities on the site.

GEOPHYSICAL SURVEYS

Three geophysical surveys were performed. Prior to the first survey, a registered land surveyor used steel rebar to stake the seven corners of the boundary of the landfill. These corners serve as

a common reference for each of the geophysical surveys.

The first geophysical survey, a conventional magnetometer survey, was completed in 1988 by an environmental consulting firm (Results of Site Investigation ..., 1988). Referenced to the seven corners of the landfill, measuring tapes were used to lay out a 3 m by 3 m grid. Data were collected at each node using an OMNI IV proton precession, total field magnetometer. Magnetic readings were also recorded several times a day at a base station to determine diurnal variations in the background field values.

During the survey, the locations of visually obvious surface ferrous materials were also recorded. These surface materials included such items as an abandoned jeep and metal warning signs; the reason these materials were not removed prior to the survey is unknown.

The second geophysical survey also used total field magnetometers to collect field data. The site was cleared of surface ferrous materials prior to the second survey. The NRL, Geo-Centers Inc. and Sandia National Laboratories conducted a field demonstration of the Multi-sensor Towed Array Detection System (MTADS) at RB-11 in September of 1993 (McDonald, et al., 1994). This field demonstration was conducted using government-supplied hardware in conjunction with the STI system marketed by Geo-Centers Inc. of Newton, Massachusetts.

The MTADS consists of an array of seven cesium-vapor magnetometers mounted on a 3 m wide trailer and towed by a low magnetic signature all-terrain vehicle. Onboard computers sample magnetic field measurements from each Geometrics 822 magnetometer *twenty times per second*. An eighth, stationary magnetometer at a clean location continuously records diurnal variations in the background field. The onboard computers also log the pitch, roll, direction (fluxgate compass) and position information from a satellite-based global positioning system (GPS). With a static unit and a roving unit, the Trimble 4000 SSE GPS provides real-time location accuracy of ≤ 1 m at 1 Hz almost 100% of the time and ≤ 0.5 m accuracy 50% of the time (McDonald, et al., 1993). These accuracies can be improved with post processing.

With the MTADS, the distance between sampling nodes is fixed at 0.5 m perpendicular to the line of travel and, parallel to the line of travel, varies with vehicle speed. At 11 kilometers/hour (7 miles/hour) the effective grid is 0.5 m by 0.16 m. This rate provides about 60,000 measurements per acre, assuming no overlap. The MTADS surveyed RB-11 at a rate of *about one acre per half-hour*. On a good day, the system can collect over 1,000,000 spatially correlated measurements of the magnetic field.

The third geophysical survey was conducted in June of 1994 using a Geonics Ltd. EM61 high resolution time-domain metal detector (Hyndman, 1994). The EM61 was deployed on a Geonics trailer which is pulled by the operator. Data were collected on parallel lines 1 m apart; a tic wheel triggered the data acquisition on 0.2 m intervals to define a sampling grid of 1 m by 0.2 m.

The EM61 is marketed as an extremely high lateral resolution instrument which can detect a single 55 gallon drum at a depth of more than 3 m beneath the instrument (EM61 High Sensitivity ..., 1994). As a field test, the EM61 was used to survey a 0.3 hectare (0.9 acre) section of RB-11. This 0.3 hectare area was chosen for its isolated deep ferrous targets, and its large ferrous targets exhibiting magnetic signatures with low lateral resolution.

DATA PRESENTATION

Figure 1 is a contour map of the anomalies in the strength of the magnetic field at RB-11. This

map was produced from data collected on 3 m centers. An average background value of 52,500 gammas was subtracted from the field measurements and the data were contoured using the Spyglass Transform contouring package. As defined in the 1988 report, anomalies attributed to visually obvious surface ferrous materials have been cross-hatched. Individual targets are labeled and the boundaries of the landfill as well as the 0.3 hectare region surveyed with the EM61 are outlined.

Figure 2 is also a contour map of the anomalies in the strength of the magnetic field at RB-11. This map was produced from data collected using the MTADS with the magnetometers set at a height of 0.53 m. Time-varying background values were subtracted from the field measurements and the data were then contoured using the Spyglass Transform contouring package.

Figure 3 is a contour map of the data collected in the 0.3 hectare area using the EM61. This image depicts the response of the EM61's main coil subtracted from the response from the focussing coil, in millivolts (mV). This difference was contoured using the Spyglass Transform contouring package. The lowest contour interval is a very sensitive 0.0 mV (the data went down to a -4 mV).

DATA ANALYSIS TECHNIQUES

Magnetometer data are typically analyzed qualitatively (Hempen and Hathaway, 1992). In performing qualitative analysis, the geophysicist mentally merges prior geophysical experience with site specific information. Such interpretations are usually provided in relative terms such as large or small. Qualitative interpretations are not necessarily repeatable as three geophysicists may provide three different interpretations of the same data.

Quantitative analysis of magnetometer data has typically been limited to the two-dimensional matching of profiles. An idealized response profile is compared to the profile obtained from field data, for example (MacLean, et al., 1991). Computers allow three-dimensional model matching, where the spatial distribution of magnetometer values from a field survey are compared to the spatial distribution of values from an assumed target. The best match between the field data and the assumed or modeled target provides the quantitative interpretation of the buried object.

Researchers at New Mexico State University (NMSU) have developed pre-commercial public domain software for analyzing and interpreting data from site surveys, including magnetometer data. The Multi-sensor Analysis Program for Environmental Restoration (MAPER) employs a forward distributed dipole model (McMahon and McIntire, 1966) to simulate the surface magnetic response due to buried objects in the far field. The distributed dipole model assumes all targets to be three-dimensional steel bounding boxes or rectilinear shells with 1 millimeter wall thickness. These simulated rectangles are placed at various subsurface locations and given various sizes; surface responses are simulated based on these target characteristics. This process is repeated until the best match is found between the simulated response and the actual field data. Targets are quantified in terms of location (x, y, z) and dimensions (length, width and thickness). Although not undertaken for this study, MAPER can utilize information from multiple sensors (e.g., GPR and Mag.); extracting the parameters which each sensor is best at providing.

The magnetometry data collected by the MTADS were analyzed using MAPER. These same magnetometer data were also analyzed using another three-dimensional model matching code employed by the NRL. The NRL/MTADS simulation code uses an iterative least-squares procedure for matching field data to individually modeled dipoles in the far field. This point dipole model assumes that all targets are single points of varying depths and masses. Targets are quantified in

Figure 1 - 1988 Magnetometry Survey, 3 m. grid, see text for details

Figure 2 - MTADS Magnetometry Survey, > 0.5 m. grid, see text for details

Figure 3 - EM61 Survey, 1.0 x 0.2 m grid (focussing - main), see text for details

terms of location (x,y,z) and mass.

Geonics markets an algorithm for the interpretation of the EM61 data. Such analysis is said to work best for single targets less than a meter wide (which we believe describes many of these targets). The authors do not currently have access to this algorithm.

DATA ANALYSIS

Qualitative Analysis

All three data sets contain clusters of data points significantly above background values; all three surveys successfully verify that the area had been used as a landfill. If the purpose of the survey was to locate "large" buried objects at RB-11, the MTADS and EM61 surveys were successful; the magnetometer data collected on 3 m centers would have been successful except the presence of surface ferrous materials disqualifies much of the survey area. The following discussion is limited to the 0.3 hectare area which was surveyed by all three techniques.

The most interesting anomalies detected at RB-11 are the two curved lines that cut across the landfill as shown in Figure 2. These linear anomalies were a mystery when they were first encountered. Some field research revealed the presence of electrical cables, about two centimeters in diameter and about 0.8 m deep. These non-ferrous cables are apparently the undocumented remains of a military experiment. The cables are not energized and the magnetometers apparently detected some type of "Earth-induced" electromagnetic field. Neither the conventional magnetometer survey nor the EM61 detected these buried cables.

The 1988 conventional survey (Figure 1) and the MTADS survey (Figure 2) were "identical" except for the sampling grid. The finer sampling grid provides higher resolution images of the buried wastes and allowed the detection of more burials than either of the other two surveys. Both of these conclusions are visually intuitive.

Without numerical analysis of the lateral edges of anomalies, the EM61 provided the best definition of the edges of anomalies, as expected. Unfortunately, the instrument was not sensitive enough to detect the electrical cable or the targets 11 (T11) and T12 (it is not clear why the EM61 did not detect T12). Very small responses, 0.0 mV, were measured in the vicinity of T1, T6, T7 and T8. Without prior knowledge (e.g., Figure 2) these responses would not have been identified as burials by most interpreters.

Quantitative Analysis

The MTADS data was numerically interpreted using both the MAPER algorithm and the MTADS algorithm. Table 1 presents the results of this analysis. Interpretation of the conventional magnetometer data was not possible due to the sparsity of the data (discussed later); this is reflected in the shape of the contoured magnetic anomalies.

Table 1
Quantitative Analysis of
MTADS Data

Target	MTADS depth ¹	MTADS size ²		MAPER depth ³	MAPER shell dimensions L x W x Thickness	MAPER mass kg
1	1.7	lg		1.4	0.5 x 0.5 x 0.3	10
2	0.3	sm		0.5	0.4 x 0.8 x 0.1	11
3	0.6	med		1.1	0.8 x 0.8 x 0.2	23
4	2.2	?		1.5	1.4 x 4.7 x 1	225
5	0	drum		0	exposed drum	-
6	0.5	sm		2.1	1.0 x 1.0 x 0.3	36
7	0.3	sm		1.0	0.5 x 1.0 x 0.3	18
8	2.5	lg		2.5	0.4 x 1.6 x 1.0	27
9	3.4	lg		2.9	0.3 x 1.3 x 1.4	20
10	1.0	lg		1.3	0.3 x 1.3 x 0.5	15
11	3.8	lg		3.7	1.0 x 2.0 x 0.7	74
12	1.5	lg		1.8	3.0 x 2.0 x 0.5	213

Footnotes 1. all lengths are in meters. 2. small is < 60 mm mortar, medium is 105 mm, 45 kg, and lg is > 114 kg, 3. depth to center of mass

Missing from this table is x, y location of each anomaly. MTADS and MAPER programs automatically identify the location of each anomaly in the appropriate coordinate system. For example, T1 is located at 35° 0.40737 latitude and 106° 31. 10213 longitude (NAD 83). Because of the limited space for text, the locations of all 12 targets are not printed here. The ability to automatically generate target maps with coordinates for each target is an advantage of these two algorithms over generic contouring packages.

None of these targets have been excavated; therefore, predicted target characteristics can not be compared to actual target characteristics. So how good is the numerical analysis? In an unpublished study conducted at Twentynine Palms Marine Corps Base, the NRL found the point dipole algorithm to be very accurate for analyzing buried ordnance. Several observations can be made here which support the numerical analysis. The wastes that were analyzed as being buried deeper than 3 m (T9 and T11) are both in the same trench. Also, the large burial (T11) that was analyzed as being 3.8 m deep was undetected by the EM61 (why the EM61 did not detect the shallower T12 is unknown). Other tests are being conducted to test the validity of these algorithms.

Numerical analysis does provide a number of very important advantages over qualitative analysis.

First, targets can be quantified. Ambiguous descriptions like "large and fairly deep burial" are replaced with quantitative descriptions like "300 kg ferrous object buried at 2.5 m". Threshold criteria (e.g., excavate only targets greater than 10 kg) can then be applied to site cleanup. Second, numerical analysis allows the user to interpret or "see" individual targets instead of the magnetic dipole expression of targets. At this landfill, the ability to see individual targets puts magnetometry data and EM61 data on even footing, with both providing discrete target locations. Third, and very important for quality control, numerical analysis can be reliably repeated. Finally, numerical analysis is an important tool in the data interpretation tool chest; numerical analysis should never be viewed as the only tool in the tool chest.

COMPARISON BETWEEN TECHNIQUES

Figure 4 is an 8 m by 20 m area of the landfill capturing targets 9 through 12. Figure 4 is a *presentation of the raw or uninterpolated data* from each of the three surveys where individual data points are enlarged and given false color related to the field readings. The apparent shifting of data in the top image is probably the result of inaccuracies in locating the original grid in 1988.

Many of the advantages of collecting high density magnetometer data are visually obvious. First, small ferrous targets, like T10 can be detected. Second, the actual shape of anomalies in the magnetic field are measured, not created by the contouring package. Capturing the spatial distribution of magnetic values allows more accurate numerical analysis of burials. Third, total field magnetometers are more sensitive (i.e., detect deeper ferrous targets) than the EM61.

RECOMMENDATIONS AND CONCLUSIONS

Several areas of additional work were identified. Determining the nature of the "Earth-induced" electromagnetic field generated in the buried cables would be interesting. Numerical analysis of the EM61 data and a comparison of that analysis to the magnetometry data would be useful. Finally, additional research needs to be conducted to "validate" the numerical codes for analyzing the magnetic responses from extended targets (i.e., trench burials).

At this landfill, the magnetometer data collected on a fine grid provided several clear advantages over both conventional magnetometry data and EM61 data. First, smaller ferrous targets can be detected (e.g., T10). Second, the actual shape of anomalies in the magnetic field is measured, not created by the contouring package. Capturing the spatial distribution of magnetic values allows better numerical analysis of burials. Finally, total field magnetometers can detect deeper targets than the EM61. Based on this survey, the EM61 may not be as sensitive as indicated in the marketing literature. In summary, for characterizing landfills, magnetometry data should be collected on 1 m or finer grid.

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REFERENCES

The references cited in this paper can be found in the References section of the larger report (Adaption of the Magnetometer Towed Array ...).

1988 Magnetometer Survey

MTADS Magnetometer Survey

EM61 Survey

Figure 4 - Samples of Raw (Uninterpolated) data from each survey
115/116

Appendix I Termination of Funding

Department of Energy
Washington, DC 20585

DEC 21 1994

John Cochran
Sandia National Laboratory
Department 6331
Mail Stop 1345
Albuquerque, New Mexico 87585

Dear Mr. Cochran:

I have enclosed for your information a copy of the December Fin Plan for the Mixed Waste Landfill Integrated Demonstration (MWLID). As you will see there are several projects that have been zeroed out, but hopefully this will only be temporary. I would like to use the rest of this letter to explain why there was another budget cut and the logic behind the budget decisions.

First of all, we have now been cut by over 30% from the original planning level. Our first cut took place the day before the October Fin Plan was to be submitted. That cut was in response to reduction/tax on the program directed by Grumbly. This 20% cut is supposed to be reinstated in the 3rd quarter. If it does not become a reality by May, 1995, Clyde Frank has indicated it will not be sent out until October, 1995. This second cut of 10% was required to meet obligations committed to by EM-50 management. Our response to this cut is to not take another cut on all the programs. Instead, we have decided to not fund several projects so that other projects can be fully funded and completed.

The criteria for these decisions was discussed by the 2 focus areas, Plumes and Landfills, that the MWLID falls under. Their criteria included keeping a focussed program, politics (self explanatory) and the status of the project in terms of transfer and commercialization. Not one factor was more important than the other. As part of focussing, the Plumes organization has targeted heavy metals with radionuclides, DNAPLs with radionuclides and barriers as top priority. Landfills has indicated that covers and barriers are their top priority.

I know several of you are deeply affected and have met all of the requirements for customer and private industry involvement. Unfortunately things had to be cut. I wish it were different, but it isn't. The amount of unobligated carryover was less than anticipated, thus the 10% cut was required.

The last items include the new "gate process" for technology development, a copy of which I have included for your review. This gate process will require documentation of completion of requirements at each gate prior to continuing to the next gate. All of the requirements have not been decided, but when they are completed, I will share them with you. Included in this will be a template for commercialization plans for each gate. Your participation and submission of commercialization plans has been a big help for use in this new gate process.

Thanks for your cooperation. The only other item is that for FY95, I would recommend all funds be spent and out the door prior to September 30. There is a rumor that any funds, whether obligated or not, will be returned to headquarters for re-distribution. Please manage your spending accordingly.

That is all I have for now. If funds become available, we will re-allocate as soon as possible. Thank you for all of your efforts and if you have questions, feel free to call me at (301) 903-7248.

Sincerely,

Skip Chamberlain
Program Manager
Mixed Waste Landfill
Integrated Demonstration
Office of Technology Development

cc: J. Nelson, SNL

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