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Man-Portable Adjuncts for the *MTADS*

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With support of the ESTCP UXO Cleanup Project 1998-11, man-portable adjuncts to the vehicular MTADS have been developed. Both CS-vapor magnetometers and modified versions of the EM-61 time-domain sensors are employed. Both GPS and acoustic navigation systems have been integrated to allow surveys in areas with rugged terrain or in the open woods. The data analysis system has been modified to import data from either the vehicular or the man-portable systems using either acoustic or GPS navigation. Intermediate prototypes for each system were developed and evaluated in a clearance demonstration on a fuze testing range at the Army Research Laboratory at Blossom Point, MD. With support of a CRADA program, final field-worthy prototypes were developed which incorporated significant ergonomic improvements. The systems were evaluated against other sensor technologies in an extended demonstration at the Jefferson Proving Ground during the summer of 2000. This document is the final report for the man-portable adjuncts for the ESTCP program and for the MTADS CRADA with Blackhawk Geometrics.

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Man-Portable Adjuncts for the *MTADS*

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1. Introduction

1.1 Background

The U.S. Army Corps of Engineers – Huntsville (USACOE) estimates that approximately 20 million acres of land are contaminated with unexploded ordnance (UXO) or ordnance explosive waste (OEW) within the continental US. This is the result of a variety of operations including training, testing, manufacture, storage, disposal and intentional burials. Now, either through congressional mandates such as the formally used defense sites (FUDS), base realignment and closure (BRAC) or state litigation, these sites must be evaluated, remediated, as required, and certified as safe for the intended ultimate public use. This is a very slow and costly process, and in some cases, impossible to do with existing technologies and resources.

The Environmental Security Technology Certification Program (ESTCP) has the goal of its UXO Cleanup Thrust developing automated, more economical, and more efficient methods to accomplish UXO site cleanups through the demonstration and fielding of new technologies. One of these funded programs was the Multi-sensor Towed Array Detection System (*MTADS*) developed by the Naval Research Laboratory.[1] This system consists of a tow vehicle, two low self-signature tow platforms; one for an eight sensor magnetometer array, the other for a three sensor time domain electromagnetic (EM) pulsed induction array. *MTADS* uses GPS for navigation, sensor position locations, and survey guidance, and a sophisticated data analysis system for interpreting the field data. Analysis produces target reports and a variety of graphics products. The target analyses include target positions, depths, and orientations. In addition, predicted target size and a "goodness of fit" value show how well the target can be represented by a dipole model.[2] This system was demonstrated for ESTCP at the NRL's Chesapeake Bay Detachment at Chesapeake Beach, MD in October 1996;[3] at the Marine Corps Air Ground Combat Center, Twentynine Palms, CA[4] in December 1996, and at the Jefferson Proving Grounds, Madison, IN in January 1997.[5] Additionally, the *MTADS* was successfully demonstrated on the Badlands Bombing Range, on the Pine Ridge Reservation, in South Dakota in July 1997;[6] at the former Fort Pierce Naval Amphibious Base, Vero Beach, FL in January 1998;[7] the former Buckley Field, Aurora, CO in June 1998;[8] the Laguna Pueblo Reservation in New Mexico in July 1998;[9] at the Portsmouth Naval Shipyard, in Kittery, ME in October 1998;[10] at the JPG IV Data Fusion Demonstration, in October 1998;[11] and at the Walker River Reservation, in Nevada[12] in November 1998. Based on the success of these field demonstrations NRL signed a CRADA with a commercial company, and a non-government system has been designed and built based on the NRL *MTADS*. It is currently available for commercial use.[13]

The USACOE has recently estimated that vehicle towed-array survey systems can be used effectively on only about 30% of the UXO-contaminated land because of rugged terrain, buildings on or near the site to be surveyed, or wooded sites. GPS navigation systems do not operate effectively without a clear view of the sky, limiting the use of systems like *MTADS* under forest canopies. ESTCP funded NRL to develop an *MTADS* man-portable magnetometer system (MMS) in FY 98 and a man-portable EM system (EMMS) in FY 99. Each of the systems is being implemented with both GPS and a new acoustic navigation technology to allow surveying in areas without sky view. The system hardware designs have been carefully planned to allow MMS and EMMS data to be incorporated with vehicular survey data. This has required implementation of a new data acquisition system for both the vehicular and the man-portable systems and modification of the data analysis system (DAS) to incorporate and seamlessly overlay all data sets.[14]

In conjunction with this program, and other ESTCP and SERDP UXO programs being managed by NRL, a new ordnance test range was established at the Blossom Point facility of the Army Research Laboratory. This is the depot site for the *MTADS* and supports on-going development activities for the *MTADS* system that take place outside the laboratory environment. The test site, known as the Magnetic Test Range, is described in a separate document.[15] The Magnetic Test Range was very important for benchmark testing of the Man-Portable systems during their development, and has served for test and evaluations of numerous other systems being developed by SERDP and ESTCP by other organizations.

In August 1999 the Man-Portable systems were evaluated in a demonstration at the L Range at Blossom Point, MD. This demonstration, described in the Technology Demonstration Plan,[16] was conducted jointly with another SERDP program demonstration.[17] The results of the L Range demonstration revealed some development short-comings of the Man-Portable systems. The results of the L-Range Demonstration have been documented[18] and will be further discussed in the body of this report. The L-Range demonstration led to a final year of development and refinement of the Man-Portable systems and a final demonstration of both adjunct systems at the Jefferson Proving Ground[19] in August 2000.

1.2 Official DoD Requirements Statement

The Navy Tri-Service Environmental Quality Research Development Test and Evaluation Strategic Plan specifically addresses under Thrust Requirements l.A.1 and 1.A.2, the requirements for improved detection, location and removal of UXO on land and under water. The index numbers associated with these requirements are 1.I.4.e and 1.III.2.f. The priority 1 rankings of these requirements indicate that they address existing statutory requirements, executive orders or significant health and safety issues. Specifically the requirements document states:

> *There are more than twenty million acres of bombing and target ranges under DOD control. Of particular concern for the Navy are the many underwater sites which have yet to be characterized. Each year a significant fraction (200,000-500,000 acres) of these spaces are returned to civilian (Private or Commercial) use. All these areas must be surveyed for buried ordnance and other hazardous materials, rendered certified and safe for the intended end use. This is an extremely labor intensive and expensive process, with*

costs often far exceeding the value of the land.... Improved technologies for locating, identifying and marking ordnance items must be developed to address all types of terrain, such as open fields, wooded areas, rugged inaccessible areas, and underwater sites.[20]

The *MTADS* addresses all aspects of the Tri-Service Requirements for land-based buried UXO. It is designed to rapidly and efficiently survey large sites, with commensurate economic benefits. Moreover, it is capable of detecting all classes of buried UXO at their maximum likely penetration depths. The system will correctly locate buried targets, determine their burial depths, classify the likely ordnance size, and provide for future target way pointing, as well as create GIS-compatible target output maps and sorted target tables. The man-portable adjuncts described in this document were designed to allow this capability to be extended into areas of rugged terrain and areas with poor sky visibility.[14]

1.2.1 How the Requirements Were Addressed Since there are many common components between the MMS and the EMMS, they were developed under a single program management plan. System performance specifications were developed that we felt would provide acceptable performance for instruments that could be used in commercial service. The performance specifications are documented in Table 1.

1.3 Objectives of the Demonstration

The great strengths of the *MTADS* are its sensitivity which allows detection of all ordnance to its maximum self burial depths, the position location accuracy of the navigation and positioning system, and the target analysis algorithms which allow location of buried objects to within the actual ordnance volume, and the analysis output products which provide for the efficient reacquisition and remediation of the targets. It was a design goal for the man-portable projects to preserve the detection sensitivity for buried ordnance while extending the survey capability to include rugged terrain and open forest areas. Furthermore, new hardware and software were developed and the existing DAQ and DAS capabilities have been modified to allow integration of vehicular and man-portable data for simultaneous analysis with a single analysis software utility. The projects described in this report were designed to demonstrate these objectives.[14]

A secondary objective of the program is to transition the technology to the commercial sector. A CRADA was signed with Blackhawk Geometrics to create a commercial version of the NRL *MTADS* vehicular system.[21] This system currently exists and is providing services to the government on former ranges. A separate phase of the CRADA contains provisions for joint development and transition of the man-portable adjuncts being demonstrated here. Therefore, transition of the man-portable adjunct technology is assured. CRADA funds, in part, supported the developments described in this document.

Table 1. System Specifications and Requirements for the *MTADS* Man-Portable Adjuncts.

System Specification/Requirement	MMS	EMMS
Continuous Operating Time	2 hours	2 hours
Survey Area (Single Setup)	1 Acre	1 Acre
Lane Spacing	0.5 m	0.5 or 1.0 m
Sensor Sensitivity	0.1 nT (same as vehicular *MTADS*)	Scalable to vehicular *MTADS*
Sensor Data Rate	10 Hz	10 Hz
Navigation Data Rate	GPS/5 Hz, Acoustic/1 Hz	GPS/5 Hz, Acoustic/1 Hz
Sensor Position Accuracy	GPS 0.1 m, Acoustic 0.25 m	Same as MMS
Sensor height above ground	0.25 m (fixed)	0.25 m (fixed)
DAQ	Compatible with vehicular DAQ based on modified Geometrics 858 data recorder	Same data recorder as the MMS
DAS	Seamless integration with vehicular data	Same as MMS

1.4 Regulatory Issues

There are no regulatory issues unique to the man-portable *MTADS* adjuncts. The primary challenge is to gain the recognition and approval of the Army Corps of Engineers for these technologies so that future RFPs for UXO range projects will be written in a manner that will either sanction these technologies, or at least allow their inclusion in proposals for site work.

2.0 Technology Description

2.1 Background and Applications

Since there are many common components between the MMS and the EMMS, as mentioned above, they were developed under a single program management plan. The primary platform for each sensor involves a wheeled cart. This approach, we feel, provides for the smoothest operation, allows coordinated deployment of all sensor and navigation hardware during surveys, and maintains the sensors at a fixed height above the ground. The sensor dimensions and the array design were limited to the width of a person's shoulders based upon the premise that the system should be deployable in areas where a person could easily walk. An exception was made for the EM sensor, as described below.

2.2 System Component Descriptions (For the L Range Demonstration)[22]

2.2.1 Sensors The magnetometer sensors chosen for the MMS are Geometrics 858 ROV Cesium Vapor magnetometers, identical to those on the *MTADS* vehicular system. New EM sensors were developed with Geonics, Inc for this project. A 1m X 1m coil system was purchased which had the same performance characteristics as the individual EM units on the vehicular array. A second coil system was ordered with dimensions of 0.5 X 1.0 m. This system was designed so that the wheels could be mounted either along the short or the long coil dimensions. This allowed the system to be used as a 0.5 m wide instrument in tight or confined spaces or as a 1.0 m wide system in more open applications. The sensitivity of the 0.5 m coil system was supposed to be increased by addition of additional turns in the transmit coil. An initial demonstration was conducted at the L-Range (a mortar and fuze test site) at Blossom Point, MD. Based upon a disappointing performance in the L-Range demonstration the EM coil was subsequently replaced with a new 0.5 X 1.0 m instrument which replaced both the older coils. This new system is described in Section 6 of this document.

2.2.2 Platforms Both the MMS and the EMMS are intended to be operated primarily with the sensors mounted on two-wheeled carts. The sensors and the navigation antennas are mounted on the cart. Batteries and navigation hardware are mounted in a specially designed backpack worn by the operator. Several concept designs were assembled from PVC tubing and other plastic components until a preliminary design was fixed. At this point a prototype magnetometer cart was designed and procured from a plastics fabricator. The prototype MMS survey system is shown in Figure 1 operating with the GPS navigation system. Subsequent to the L Range Demonstration, the MMS was completely redesigned. The redesigned system is described in Section 6.

Figure 1. The MMS prototype system deployed at the L-Range Demonstration.

The commercial Geonics EM-61 coils are delivered with a two wheeled transport system. This design, as shown in Figure 2, was used for the prototype instruments. Either the 0.5 X 1.0 m or the 1.0 X 1.0 m coils were designed to be usable as a single cart. The cart and antenna support system is designed to rigidly hold both the top and bottom coils in place, with the GPS or acoustic antenna mounted centered above the

Figure 2. The EMMS prototype system deployed at the L-Range Demonstration.

upper coil. Rigidity is required because the GPS antenna has a significant signal at the upper coil which must be nulled as part of data preprocessing. Because of the excessive weight of the system batteries and the GPS instrumentation, the equipment was split between two backpacks for the L Range demonstration, as shown in Figure 2. When using the acoustic navigation system all equipment was accommodated in a single backpack and only a single operator was required to take survey data. As a result of the demonstration at the L Range, the EMMS was replaced by a new instrument as described in Section 6.

2.2.3 DAQ The backbone of the Man-portable survey equipment is the modified Geometrics 858 data recorder, Figure 3. The standard Model 858 commercial system is configured with dual cesium vapor sensors, which can be used as two separate magnetometers or in a gradiometric configuration. The off-the-shelf 858 also comes with one RS-232 COM port access to the palm-top data storage device. Two battery packs are included with an operating time of six hours each. The data logger stores 2.5 Mb of data or about 4.5 hours in the MMS configuration in which the GPS is recorded at 5 Hz and the sensors at 10 Hz, in up to five separate files. The single COM port provided with the standard unit is suitable for GPS or manual input of ASCII text.

The Model 858, modified for use with the MMS and the EMMS, incorporates three more COM ports to accommodate the additional data inputs needed for the MMS. These COM ports are included in the 858 battery (9 pin) connector. The original COM port, located in the data out/GPS connector (8 pin), is called COM Port 1. The first port in the battery connector is called Port 2 and in the MMS is used for the GPS GGK string input at 5 Hz. Port 3 is used to input the 1Hz acoustic navigation data from the USRADS Data Pack. Port 4 is used to input the 1 pulse per second from the Trimble 7400 receiver or the sync pulse from the acoustic navigation system. The system software has been modified to trigger the data stream from the EM61 through COM ports.

When the MMS is deployed with GPS navigation, all data are recorded on the 858; the 2 mag sensors, the 5 Hz GGK string from the Trimble 7400 (PWR I/O 1) and the 1 PPS (Aux port). All data are downloaded through COM Port 1 in binary format. When the MMS is deployed with the USRADS acoustic navigation system, the record number generated by the transmitter is recorded in the 858 *via* COM port 3 along with the sync pulse through the 858 COM port 4. Positions (tagged with the record number) are derived at the remote site and combined in the DAS. The Geometrics data logger can either be mounted on sensor platform as shown in Figure 3, or can be worn in a "fanny pack" on the waist of the operator as shown in Figure 2.

Figure 3. The Geometrics Model 858 data logger serves as the DAQ for both the MMS and the EMMS deployed with either the GPS or acoustic navigation systems.

2.2.4 Navigation Trimble Model 7400 GPS receivers, currently used by the vehicular *MTADS,* were used for the primary MMS demonstration at the L Range. This system,

operating with a Model 4000 SSI base station receiver, provides the full range of GPS location options. In the highest precision fix, RTK, (level 3, Real-Time Kinematic) the base station provides a differential position fix with fully resolved numerical ambiguities. This real-time location accuracy is 2-5 cm. A level 2 fix, (Float) is accurate to 10-50 cm because some of the integer ambiguities remained unresolved in the solution. The traditional differential solution (level 4) may have an accuracy degraded to 0.5-1.0 m, depending upon the number and position of the satellites in the solution. MTADS surveys are begun only with a level 3 fix. If during the survey the fix quality briefly drops to level 2, offsets and corrections are implemented in the data cleanup process. Survey data based upon lower quality fixes are typically not used in *MTADS* surveys.

The navigation fix quality can be observed only by using the chat mode during setup. If the GPS fix quality drops below float during a survey, the operator is not informed. For the L- Range demonstration using the Trimble satellite planner allowed us to avoid poor survey times. However, this approach was deemed unacceptable because the potential exists for collecting unusable data. The display and readout options were subsequently improved, as described in Section 6.

The Chemrad Navigation System (USRADS Model 2300) provides acoustic navigation data when satellite visibility will not support GPS navigation. This system deploys an acoustic transmitter on the rover platform and a network of up to ten transponders at fixed stations about the perimeter of a survey site. The system uses time-of-flight data to triangulate among all possible pairs of transponders to create a location position which is updated at 10 Hz. Evaluation testing in wooded areas has demonstrated that the USRADS System provides navigational fixes which are accurate to ~25 cm when 10 stationary receivers (S/R) are used to enclose a one acre wooded site. Under good conditions the acoustic sensors have a range of about 200 ft. This accuracy is degraded in high wind or high noise environments or when visibility is limited by obstructions. Deployment strategies are critical for successful use of this system. See the further discussion below and in Section 5.2.4 about limitations and potential improvements of the system.

2.2.5 DAS The *MTADS* Data Analysis System (DAS) has been modified to accept the data from the MMS and is fully integrated to merge the vehicular and MMS data, or multiple MMS data sets and provide the same analysis capabilities. Once preprocessing steps have been carried out, magnetometry data from the MMS or the vehicular system (using either navigation system with the MMS) can be combined into single survey data sets. For instance, wooded areas within a larger vehicular survey area, would be completed with the MMS (and acoustic nav) and edited to fill in missed areas in the vehicular survey. In general, data from multiple surveys of the same areas are not commingled, the better data would be used for any given area.

The identical approach is not used for data taken with the EMMS. Because of the different sensitivities of the various EM coil systems, and the various deployment options, a decision was made to process EMMS data separately from vehicular EM data. The baseline *MTADS* DAS currently has all necessary utilities, routines, and switches to allow processing of data from all vehicular and man-portable setups regardless of the navigation system used to survey.

2.3 Advantages and Limitations of the Technology

The MMS and EMMS were designed to allow the *MTADS* survey capability to be extended into rugged terrain that cannot be traversed by the tow vehicle. The addition of the acoustic navigation system allows the survey capability to be extended into areas that have limited sky view, including under forest canopies. The wheeled MMS cart is designed to be pushed ahead of the operator allowing him to maneuver through fairly tight spaces. The width of the cart and sensor arrays are designed to be at or below the width of the operator's shoulders. The wider EM coils are available for areas with less severe space constrictions.

Maintaining the sensors on the carts allows for smoother operation, minimizing motion-coupled noise and errors from uncontrolled swinging motions typical of sensors mounted on a hand-held boom. On the carts a fixed relative position of the sensors with the navigation antennas is maintained. A disadvantage of this design is that access is precluded from areas that are very tight and from areas that have difficult ground cover such as brush, deep mud, or extremely rugged terrain.

2.3.1 System Limitations The MMS and the EMMS were demonstrated on the L Range at the Army Research Laboratory during the week of 13 September 1999. Part of the site was in the open near a tree line. The remainder of the site was in the woods where the acoustic system was exclusively used for navigation. In open areas duplicate surveys were conducted with each navigation system. In the MMS surveys the location accuracies and the detection sensitivity levels were comparable to the *MTADS* towed array system with the GPS navigation system. Sensor location accuracy was lower when using the acoustic navigation system. These results are described more fully in Section 5.2.3 of this report.

In conducting EMMS surveys on the L-Range, we noted that the lower sensitivity of the 0.5m X 1.0m coils significantly degraded the system performance of the EM adjunct relative to the vehicular EM array. As deployed on the L-Range, the EMMS trailing behind the operator, is unstable and side-to-side rocking motions on rough ground produced location inaccuracies because of antenna displacement. The EMMS was relatively difficult to navigate in the woods because it trails behind the operator and is side-to-side unstable. It is difficult to maneuver through close areas because the operator cannot see when the coils or the wheels are becoming entangled in brush or going to be trapped by trees.

In addition, we identified several areas in which improvements could increase the ruggedness, reliability or long-term usability of the adjunct systems. Overall, following the L Range Demonstration, we concluded that while the adjuncts met most of the design performance specifications, they were unsuitable in their present configurations for use as commercial field instruments. We undertook numerous upgrades and modifications during FY-2000, the third year of the program, in preparation for the final demonstration. These modifications are outlined in more detail in Section 6.

2.3.2 Post Prototype Modifications The GPS navigation system, the backpacks, the cabling, the data acquisition system, and the sensor platforms were modified for both the MMS and the EMMS before the L-Range Demonstration. In addition the EM sensor for the EMMS was redesigned and the DAS was modified to process data from the new instrument. These developments are fully described in Section 6 of this report.

3.0 Pre-Demonstration Activities at the L-Range

3.1 Site Selection

Because there were limited funds available within the Man-Portable Program to support extensive demonstrations, alternatives were sought that would minimize expenses associated with transporting equipment and complex logistics support. Because compatibility of the MMS and EMMS with the vehicular survey data is an important objective, it is important that vehicular surveys be able to overlay the data taken using the man-portable adjuncts. Vehicular survey data of demonstration areas should serve as the benchmark against which the Man-Portable data is measured.

There are extensive impact ranges at Blossom Point that have been used for fuze development and testing using mortars and rockets. Some of these areas have been partially cleaned, most have not. Our setup of the Ordnance Detection/Classification Test Field clearly demonstrated that even areas not formally associated with known ranges, are also UXO contaminated.[15]

We chose an area at the ARL, Blossom Point facility for the Man-Portable Demonstration Site. The demonstration area was set up to be partially contiguous with areas selected for the ESTCP "EM and Magnetic Sensor Fusion for Enhanced UXO Target Classification" Demonstration scheduled for August 1999.[18] A part of the L-Range is shown in an aerial photograph in Figure 4. This area has long been a test range for various munitions. It is 800-ft wide by 5000-ft long, encompassing about 95 acres. The range is bordered on the south (river side) by a mixed pine and hardwood forest. The range itself is generally flat, grass covered, and is regularly mowed. The forest bordering the range varies from open woods to rugged areas with extensive underbrush. The 3-acre area designated for the ESTCP Data Fusion Demonstration is shown outlined in yellow. The MMS and EMMS demonstration areas are shown outlined in red. The entire area within the red boundary was surveyed with the EMMS and MMS platforms using the acoustic navigation system. The portion of the site accessible for use of the GPS navigation system was similarly surveyed with each portable system. The entire area within the yellow boundary was surveyed with both the magnetometer and EM *MTADS* vehicular arrays. The activities are described in the Technology Demonstration Plan[16] which is included as Appendix B on CD-ROM.

3.2 L-Range Predemonstration Sampling

Human Factors Applications, Inc., conducted an ordnance removal project at the Blossom Point Test Facility in November 1996.[23] Two areas were cleared bordering the west and north

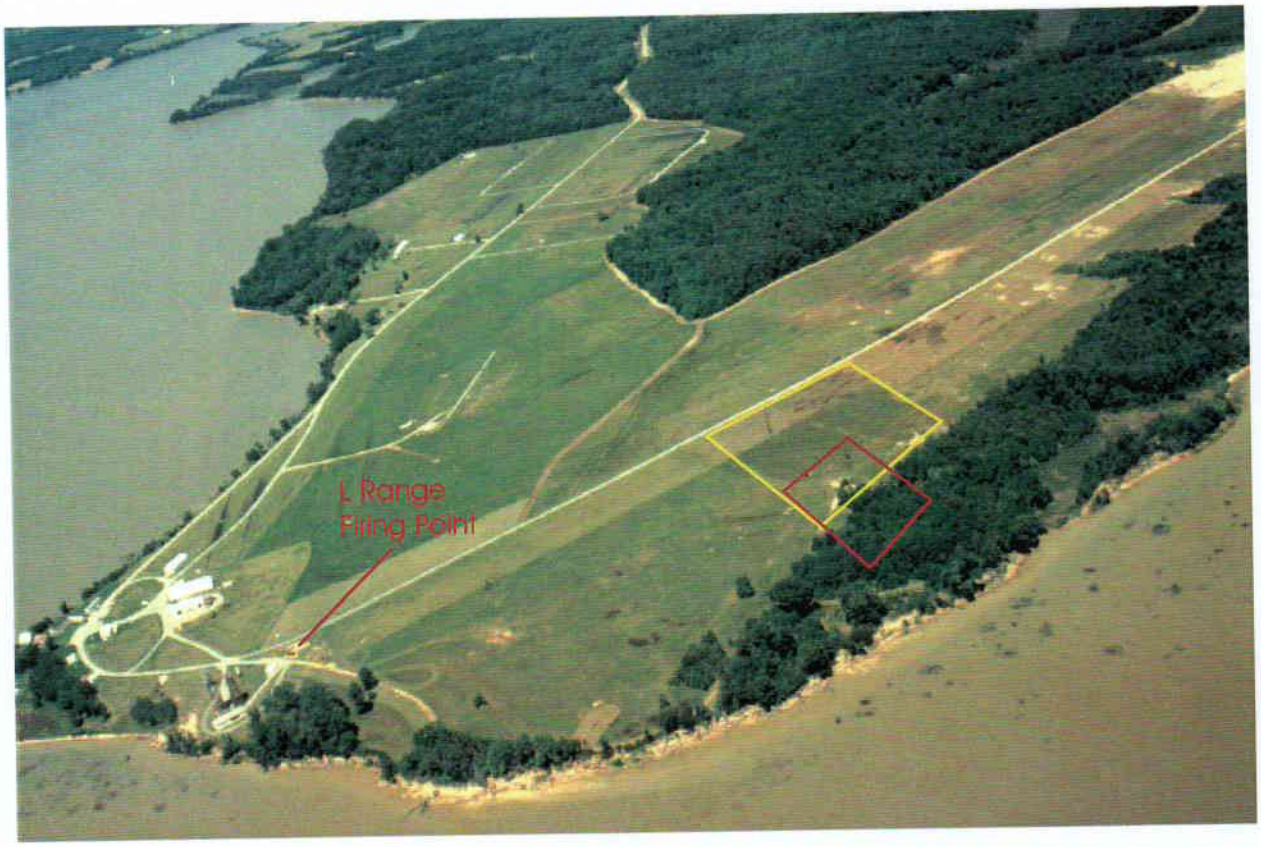

Figure 4. The L-Range at Blossom Point. The approximate area of the *MTADS* Data Fusion Survey is outlined in yellow, the Man-Portable survey area is outlined in red.

sides of the L-Range. The objective of these projects was the survey and removal of ordnance allowing construction and installation of power lines. The "Mag and Flag" remediation operation used Schonstedt Gradiometers. During the remediation, 753 live UXO items and 9,267 lbs of OE and other scrap were recovered. The surveyed areas included 36 acres of open land and 30 acres of woodlands. **Table 2** lists the live ordnance recovered. This list of ordnance represents a cross section of the items which we expected to recover from the surveys and digging associated with our demonstrations.

3.3 L-Range Predemonstration Shakedown Tests

The man portable platforms have been continuously tested during the development phase of the project against individual items in the test pit and against the NRL Ordnance Detection/Classification Test Field at Blossom Point. Because it is an objective of the program that the MMS and EMMS data seamlessly overlay with data from the vehicular system, we took benchmark surveys of the Test Field using the vehicular magnetometer and EM arrays. The magnetic test range and classification test field have been described in detail in earlier NRL publications.[15] Numerous other technologies have also been tested and demonstrated at this test site, including the Geophex, GEM 3, the Geonics EM-63 (by NAEVA), the Geonics EM-61 3D (by

Blackhawk Geometrics), an R&D time-domain instrument (by Johns Hopkins APL) and an R&D GPR system (by Ohio State/CRELL).

3.4 Site Preparation

The entire L-Range was surveyed using the vehicular *MTADS* magnetometer array. Areas, shown in Figure 4 were carefully chosen to assure that many buried targets would exist within the survey area, but that the density of buried clutter would not be so high as to preclude analysis of most buried targets as single items.[18] This was particularly important in the Data Fusion Demonstration as analysis algorithms were being evaluated that were intended to recover target shape information. The areas chosen for survey were also established such that they could be extended seamlessly into the woods to include both open and wooded areas.

3.4.1 Seeded Targets UXO benchmark items were seeded into the Demonstration area to provide additional ground truth that could be used to evaluate the relative performance of the MMS and EMMS using each navigation system. The dimensions of the survey area were expanded somewhat over those shown in Figure 4 (in red) to allow easier placement of the seed targets in relatively clear areas. Figure 5 shows a portion of the vehicular *MTADS* magnetometer survey with the new site perimeter defined in white. This image provides an impression of the densities of buried ferrous targets on the Range. The man-portable survey area extends an additional 35 meters from the shown southern perimeter into the woods.

The inert items, detailed in Table 3, range in size from M-23 (three pound practice bombs) to 105-mm projectiles. The vehicular surveys were used to choose burial sites near the woods that were relatively clear of other buried objects. Inert UXO seed targets buried in the woods were sited using hand-held metal detectors to define relatively clear burial sites. Backhoes and shovels were used to excavate, as required, for the seeded items. A commercial GPS surveyor was hired to locate the buried items as they were placed in the ground. GPS location was used in open areas. Items buried in the woods were located by laser survey equipment operating from GPS benchmarks. Orientations, and depths to the ordnance centers were recorded prior

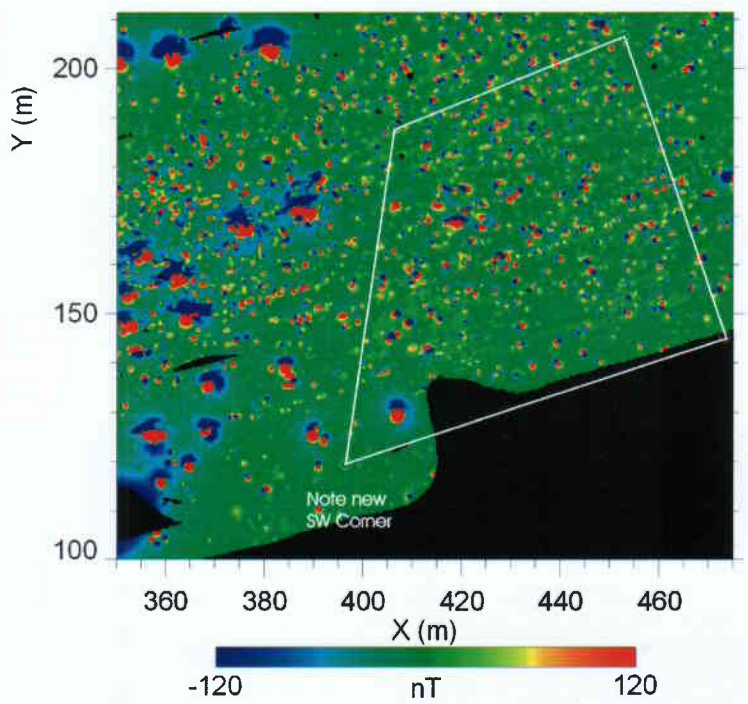

Figure 5. Magnetic anomaly map from an *MTADS* vehicular survey. The part of the man-portable survey area on the Range is bounded in white. The survey area extends an additional 35 meters into the woods.

to careful backfilling and tamping of the soil to minimize subsidence. At the same time the seed items were buried, a bush hog attached to the backhoe was used to partially clear brambles and underbrush from the wooded survey site. No trees or large saplings were removed and some areas were left with brush cover that would be difficult to walk through with the MMS and EMMS. It was expected that probably 10-15% of the wooded site would not be accessible to the man-portable instruments.

3.4.2 Preliminary Surveys Before beginning the man-portable surveys, the vehicular *MTADS* was used to again survey the area outlined in yellow in Figure 4 using both the magnetometer and EM arrays. The survey was extended as close as possible to the woods while maintaining acceptable GPS navigation fix quality. These data were used both for this Demonstration and for the ESTCP Data Fusion Demonstration. [18]

3.4.3 Establishing Survey Lanes The corners of the survey areas were established by the GPS surveyor and marked by bicycle flags. Wooden stakes were driven at 1-meter intervals along the east and west boundaries of the survey area. Twine was used to connect the east and west stakes defining the survey lanes. In the woods additional stakes were used within the site to maintain lane spacings as the twine snaked around trees and through the brush.

Table 2. Live ordnance recovered in the HFA Clearance

Number Recovered	UXO Item	Number Recovered	UXO Item
4	20-mm Rounds	3	2.36-in Rocket Motors
76	30-mm Rounds	2	2.75-in Rocket Warheads
21	CAD (explosive)	21	3.5-in Rocket
57	40-mm Rifle Grenades	1	5-in Rocket Warhead
1	M31 Rifle Grenades	1	2.75-in Rocket Motor
27	60-mm Mortars	71	Bomb Fuzes
116	81-mm Mortars	2	3.5-in Rocket Fuzes
36	4.2-in Mortars	3	81-mm Mortar Fuze
4	37-mm Projectiles	5	Fuze W/booster
4	75-mm Projectiles	4	Nose Fuzes
2	90-mm Projectiles	3	PD Fuze
3	105-mm Projectiles	2	M31 Warhead
2	106-mm Projectiles	4	Blu-7
1	57-mm Soviet Rocket Warhead	6	Blu-26

Table 3. Identification and locations of the inert UXO seed targets.

Target No	UXO ID	Location		Location (UTM)		Depth (m)	Azi. (deg)	Incl. (deg)
		Latitude	Longitude	Northing	Easting			
T-1	81-mm	38.408114616	-77.103106356	4253192.0	316371.4	0.21	45	45
T-2	M-23	38.408182890	-77.103135897	4253199.7	316369.0	0.15	0	0
T-3	4.2-in	38.408279866	-77102816841	4253209.8	316.397.1	0.63	45	45
T-4	105-mm	38.408362672	-77102673710	4253218.7	316409.8	0.69	45	45
T-5	2.75-in	38.408226790	-77.102714295	4253203.7	316405.9	0.30	90	0
T-6	M-23	38.408258385	-77.102623238	4253207.0	316413.9	0.18	45	0
T-7	81-mm	38.408306797	-77.102575035	4253212.3	316418.2	0.43		90
T-8	81-mm	38.408288164	-77.102524670	4253210.1	316422.6	0.28	0	0
T-9	2.75-in	38.408321734	-77.102495520	4253213.8	316425.2	0.28	0	45
T-10	81-mm	38.408324947	-77.102430749	4253214.0	316430.9	0.51	45	0
T-11	M-23	38.408367373	-77.102281185	4253218.4	316444.0	0.20		90
T-12	M-23	38.408374777	-77.102240512	4253219.2	316447.6	0.15	45	45
T-13	2.75-in	38.407993265	-77.102011424	4253176.4	316466.7	0.30	0	90
T-14	2.75-in	38.408122587	-77.102093780	4253190.9	316459.8	0.30	90	
T-15	M-23	38.408107204	-77.102238338	4253189.5	316447.1	0.15	0	0
T-16	M-23	38.40993279	-77.102292141	4253176.9	316442.2	0.15	45	0
T-17	60-mm	38.407977164	-77.102425350	4253175.4	316430.5	0.30	0	45
T-18	81-mm	38.407903350	-77.102445624	4253167..3	316428.5	0.48	45	45

4.0 L-Range Demonstration Approach

4.1 Performance Objectives

The performance objectives for this demonstration are very straight forward:[16]

- Conduct MMS and EMMS surveys of the entire survey area using the acoustic navigation system;
- Conduct MMS and EMMS surveys of the accessible areas using the GPS navigation system;
- Serially conduct *MTADS* target analyses for all man-portable surveys and the vehicular surveys. The vehicular EM survey data was analyzed using the 3-β classifier. Develop dig lists based upon each analysis and prepare dig images to reacquire and flag all targets picked from each survey;
- Dig all targets using UXO-qualified technicians. Document location, orientation, and identification of all recovered targets and photograph all UXO in-place before removal; and
- Analyze results to determine the relative performance achieved using each survey approach.

4.2 Physical Setup and Operation

The survey and data file log are summarized in Table 4. The open area was surveyed on 7/28/99 using the vehicular magnetometer array. On 8/03 the area was surveyed using the vehicular EM system, first in an east/west direction and then in a north/south direction. Two orthogonal EM surveys are typically used when conducting an EM 3-β analysis. Survey time periods were selected to allow vehicular surveying with good GPS coverage while working adjacent to the woods.

MMS and EMMS surveys were conducted using 0.25-meter lane spacings. During surveys using the GPS navigation system, survey times were chosen to allow good GPS coverage while working adjacent to the woods. Figures 1 and 2 show MMS and EMMS surveys underway in the 5000 m^2 open range area. As shown in Figure 2, EMMS surveys using the GPS navigation system were conducted as two-man operations because the weight of equipment was too high to comfortably carry in a single backpack. All other man-portable surveys required only a single operator and a single backpack. Reduction of weight and consolidation of all equipment into a single backpack was addressed in the system upgrade in preparation for the JPG demonstration. A single acoustic navigation beacon setup was used to conduct the MMS and EMMS surveys in the open area. The survey bounds are as shown in Figure 5. A second beacon setup was used to conduct the 3300 m^2 surveys within the woods. Man-portable surveys of the open area required 3-3.5 hours with either system. Surveys of the wooded area required about 3 hours each, including set up of the acoustic navigation system.

Table 4. Survey log for the vehicular and man-portable surveys.

Platform	Navigation	Survey Area	Files	Date	Survey Time
Vehicle/Mags	GPS	Fusion/MP Open Area	99209499 99209544 99209614	7/28/99	126 minutes
Vehicle/EM (East/West)	GPS	Fusion/MP Open Area	99215497 99215577 99215624 99215644 99215545	8/03/99	294 minutes
Vehicle/EM (North/South)	GPS	Fusion/MP Open Area	99215721 99216524 99216555 99216595 99216628 99216699	8/03-04/99	267 minutes
MMS	GPS	MP Open Area	99217002 99217003 99218003	8/05-06/99	208 minutes
EMMS	GPS	MP Open Area	99218004 99218005 99218006 99218007	8/06/99	196 minutes
EMMS	Acoustic	MP Open Area MP Open Area MP Open Area MP Open Area MP Open Area MP Woods MP Woods MP Woods	00221001 99221002 99221003 99222001 99222002 99222003 99223003 99223004	8/09-11/99	216 minutes 145 minutes
MMS	Acoustic	MP Open Area MP Open Area MP Woods MP Woods MP Woods	99224001 99224002 99222005 99222006 99223001	8/12/99 8/10-11/99	170 minutes 165 minutes

An example man-portable survey is shown in Figure 6. The areas north and east of the yellow lines were also included in the ESTCP Data Fusion Demonstration Survey. Only vehicular data were used in that demonstration, however. Area within the white perimeter line constitutes the man-portable survey area. Area south of the red line was effectively within the woods and could not be surveyed using the GPS navigation system. The largest missed survey area in the woods (at about X=110, Y=10) was excluded because it contained the decaying corpse of a large deer who expired after the seed targets were placed, but before the surveys took place. As there were no seed

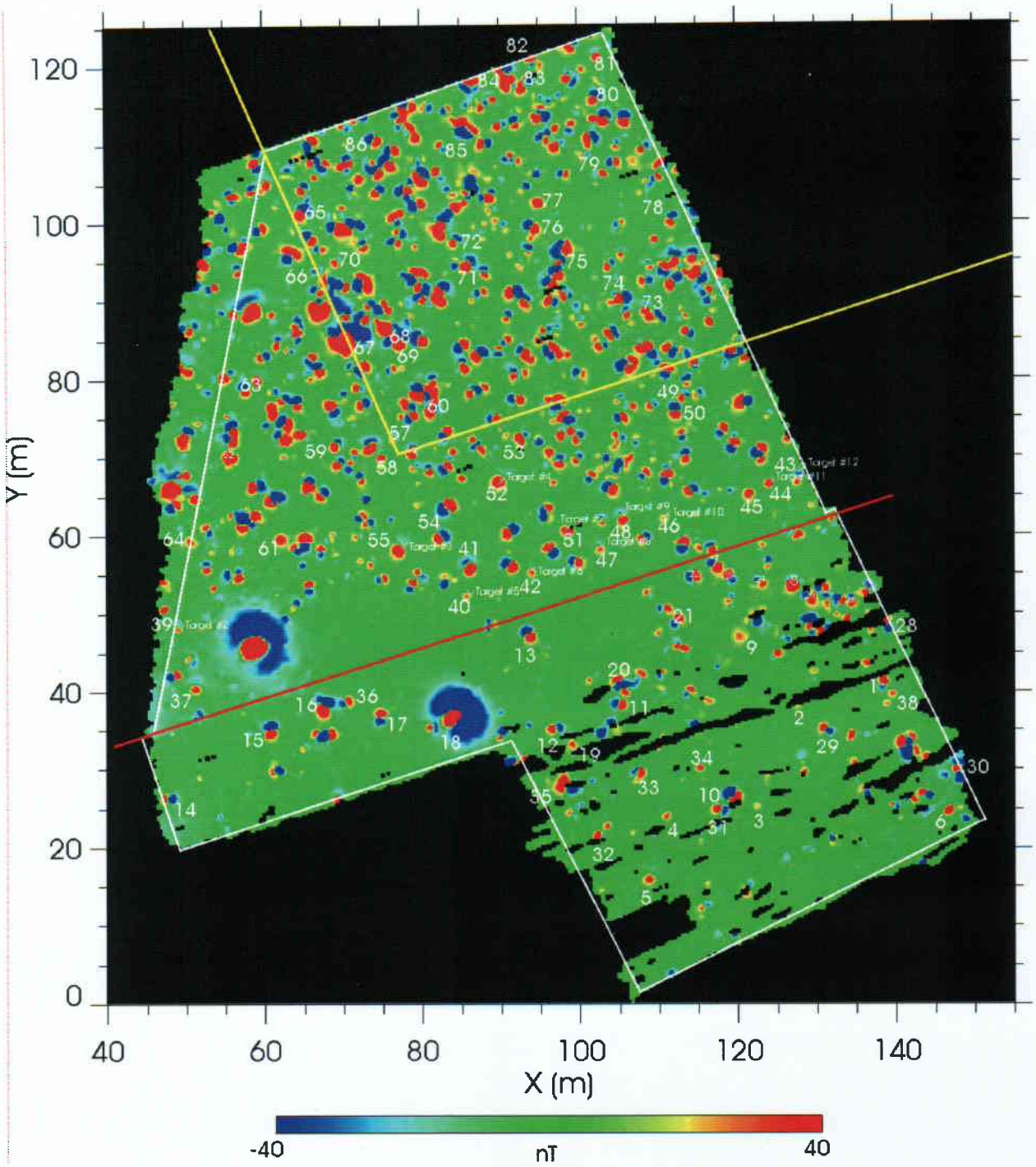

Figure 6. Magnetic anomaly image of the man-portable survey area taken using the acoustic navigation system.

targets within this area, it was not surveyed. Other apparent missed areas included groups of trees or brush areas that could not be navigated with the magnetometer cart. Some of the seeded targets are identified in the image and labeled with their target numbers.

Figure 7 shows two of the EM surveys. The east-west vehicular survey is shown on the left. On the right, the composite images from the man-portable surveys using the acoustic navigation system are shown. Two impressions are immediately apparent. The man-portable EM survey equipment is much less sensitive than the vehicular array. Note the sensitivity levels on the plots. The 0.5 X 1.0 meter coil produces peak signals 12-16 times less intense than from the vehicular array, depending upon target size and depth. The peak signal strength from the 1.0 X 1.0 m man-portable EM coils is about 4 times less intense than from the vehicular array. The sensitivity of the half and one meter coils scale directly with the area of the transmit and receive coils. Only the 0.5 X 1.0 meter man-portable coils were used in this demonstration. The results of this decreased sensitivity will become apparent when the performance of the system is analyzed.

The second visual impression left by the man portable image in Figure 7 is that the EMMS survey coverage in the woods was poor compared to the coverage of the MMS survey. This is a result of poor quality control in the survey process. Either a complete survey was not taken, or survey files were lost, leaving gaps in the coverage. The extent of the missed areas was not realized until it was too late to recover and resurvey these areas. In retrospect, the wooded areas should have been gridded twice and surveyed in orthogonal directions to improve coverage. In a real world operation, to assure complete coverage and detection of all UXO, hand surveys using fluxgate gradiometers or metal detectors would be required to survey in brushy areas and in missed areas adjacent to trees. All survey images from the L-Range are shown in Appendices on the included CD-ROM. In addition, dig images which were prepared for reacquisition of the targets for digging are presented in Appendix C.

4.3 Sampling and Analysis Procedures

Parts of the man-portable survey area were covered by 7 separate surveys; 2 vehicular EM surveys, 1 vehicular magnetometer survey, 2 MMS surveys (GPS and acoustic navigation) and 2 EMMS surveys (GPS and acoustic navigation). The area in the woods was surveyed only by the MMS and EMMS using the acoustic navigation system.

The area in the Data Fusion Demonstration (north and east of the yellow lines in Figures 6 and 7) was analyzed using the 3-β classifier and the point dipole magnetometer target fitting algorithm. 201fusion targets were chosen for analysis and digging. These included 6 of the Man-Portable Seed Targets and 24 additional targets within the man-portable survey area. These 24 targets were therefore accepted as targets in the man-portable analyses. No attempt was made in the Data Fusion Demonstration to be inclusive in the target selection and analysis. Indeed, only 10-15% of the buried objects large enough to be UXO items were chosen for analysis and digging.

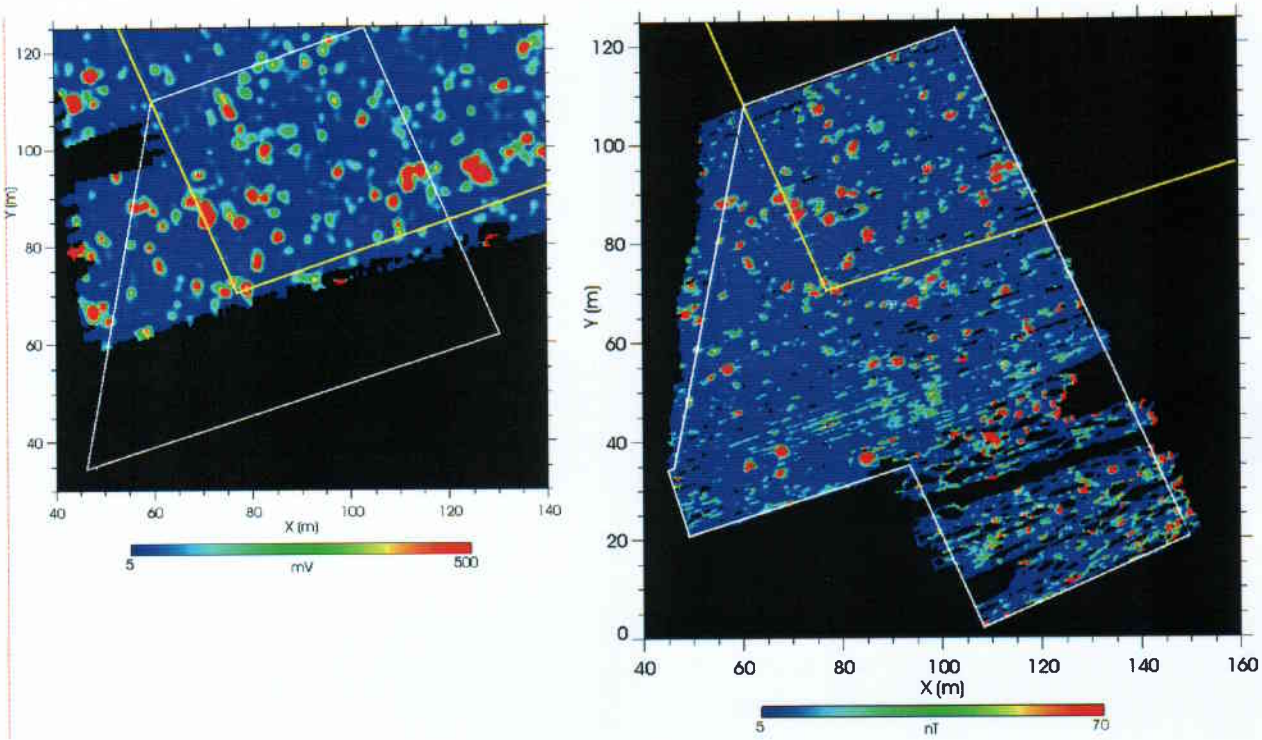

Figure 7. EM anomaly images of the man-portable survey area. On the left the vehicular survey using GPS navigation is presented. The right image shows the EM man-portable survey using the acoustic navigation system. Note the change in signal scale factors between the plots.

In the man-portable demonstration, the data from the various surveys were serially analyzed. A complete analysis of the man-portable MMS survey using the acoustic navigation system was initially carried out. The coordinates of the 24 3-β fusion targets were flagged to be certain that they were included in this and all subsequent analyses. A total of 91 targets were chosen for the dig list in the man-portable survey area. This included the 18 seed targets and the 24 3-β Fusion targets in the MMS (acoustic nav) survey.

The acoustic MMS target analysis was then carried through the remainder of the survey data sets, analyzing the same targets in each data set when the targets were visible. Some targets were not analyzed in some data sets because they fell within missed survey areas, or because the targets were not detectible or analyzable. Only the east/west vehicular *MTADS* EM data were analyzed. They were analyzed using the point dipole baseline algorithm to provide a comparison with the 3-β analysis. Figure 8 shows a portion of a magnetic anomaly image from the vehicular *MTADS* magnetometer survey. Only a fraction of the total visible targets were chosen for digging. The number of targets dug was resource limited. All targets were chosen from the Fusion Dig List and were supplemented with targets on the range that, on analysis, appeared to be likely UXO objects. Within the woods, a significant fraction of the total targets were specified for digging because the target density was much lower than on the range. Many of these targets were improbable as UXO because they had complex signatures or significant remnant moments. Target numbers in Figure 8 were from the Fusion Target Dig List, except when the target number is preceded by an "M." The M-designated targets were not considered in the 3-β Fusion Demonstration.

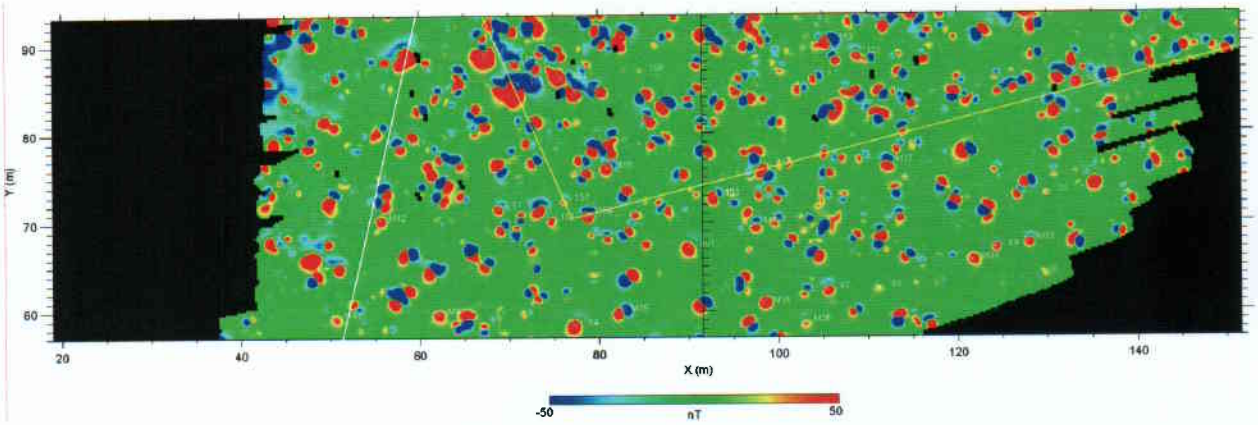

Figure 8. Composite magnetic anomaly image from the man-portable survey area. A larger copy of this image is used by the target reacquisition team and by the dig team to guide their operations.

5.0 L-Range Performance Assessment

5.1 Performance Data

In Table 5 the analyses for the 18 Seed Targets are documented. The Ground Truth entry lists the UTM coordinates measured when the UXO target was buried, and its measured depth and orientation. Each UXO item has analysis entries for all surveys in which it was detected and fit. The Fusion Analysis Demonstration covered only 6 of the Seed Targets. Targets 13-18, located in the woods, were surveyed only by the MMS and EMMS (acoustic nav) surveys.

In Table 6 the same information is provided for the 39 targets located on the Range in areas that were surveyed using at least one of the GPS-navigated surveys. Not all GPS surveys covered exactly the same areas because satellite positions are more favorable at some times than others allowing closer approach to the tree line. The listed "Ground Truth" information includes only the UXO supervisor's description of the item, its approximate depth and some orientation information. Position information relative to the flag is not included because the information provided by the dig teams was not precise or comprehensive, and the flags were positioned in some cases based upon the vehicular magnetometer survey Fusion analysis and in other cases upon the analysis of the MMS (acoustic survey) analysis.

In Table 7 the MMS and EMMS survey results are provided for the 31 targets that were on the dig list from the surveys in the woods. The 6 Seed Targets in the woods were included in Table 5. A total of 90 targets were flagged and dug by the UXO-certified remediation team. A dig sheet was filled out for each target recording the identification of the item, its location relative to the flag, and its depth and orientation. All UXO items were photographed before removal from the hole. A summary of the recovered items is included in Table 8.

Table 5. Survey Analyses for the Seed Targets.

Target ID	Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
SEED T1	Ground Truth		316371.36	4253192.02			0.53		0.081	45	45		81mm Mortar, 60 deg nose down, Pointing NE, 1.5 ft deep
81-mm mortar	Vehicle Mag EW	1	316371.24	4253191.90	51.48	40.58	0.51		0.083	40	15	0.962	
	Vehicle EM EW	1	316371.21	4253191.62	51.45	40.30	0.01	0.05	0.083				
	Fusion Fit	FUS-63	316371.21	4253191.89	51.45	40.57	0.45	0.38	0.077	44	10	0.980	
	MP Mag GPS	1	316371.27	4253191.89	51.51	40.57	0.52		0.086	47	17	0.948	
	MP Mag ACO	37	316371.07	4253191.83	51.31	40.51	0.62		0.088	43	12	0.949	
	MP EM GPS	1	316371.20	4253191.91	51.44	40.59	0.03	0.03	0.036				
	MP EM ACO	44	316371.54	4253191.58	51.78	40.26		0.00	0.018			0.545	
SEED T2	Ground Truth		316368.95	4253199.66			0.15			0	0		M23 pointing N, Flag 2.7 in N
M-23	Vehicle Mag EW	2	316369.20	4253199.63	49.43	48.31	0.17	0.05		25	334	0.87	
	Vehicle EM EW	2	316369.12	4253199.98	49.36	48.66	0.50	0.08	0.182				
	Fusion Fit												
	MP Mag GPS	2	316369.08	4253199.64	49.31	48.32	0.13		0.051	29	348	0.866	
	MP Mag ACO	39	316368.84	4253199.50	49.07	48.18	0.12		0.044	27	353	0.873	
	MP EM GPS	2	316369.24	4253199.58	49.48	48.26	0.27	0.06	0.099				
	MP EM ACO	43	316368.98	4253199.63	49.21	48.31		0.25	0.050			0.747	
SEED T3	Ground Truth		316397.06	4253209.79			0.64		0.107	45	45		4.2 in Stokes Mortar, 2.5 ft deep
4.2-in Mortar	Vehicle Mag EW	8	316397.17	4253209.84	77.40	58.52	0.76	0.12		56	50	0.945	
	Vehicle EM EW	4	316396.81	4253209.95	77.04	58.63	0.56	0.11	0.277				
	Fusion Fit	FUS-64	316397.13	4253209.74	77.37	58.42	0.79	0.51	0.118	68	63	0.947	
	MP Mag GPS	5	316397.11	4253209.74	77.34	58.42	0.68		0.112	56	41	0.956	
	MP Mag ACO	55	316396.92	4253209.52	77.15	58.20	0.81		0.115	55	39	0.970	
	MP EM GPS	5	316397.18	4253209.85	77.42	58.53	0.00	0.03	0.036				
	MP EM ACO	34	316396.65	4253209.56	76.88	58.24		0.82	0.097			0.579	
SEED T4	Ground Truth		316409.77	4253218.69			0.69		0.105	45	45		105 mm Proj. @ 2.0 ft.
105-mm Proj	Vehicle Mag EW	22	316409.85	4253218.68	90.09	67.36	0.78	0.11		48	40	0.967	
	Vehicle EM EW	10	316409.81	4253218.70	90.05	67.38	0.31	0.07	0.140				
	Fusion Fit	FUS-201	316409.84	4253218.62	90.08	67.30	0.82	0.56	0.115	58	49	0.979	
	MP Mag GPS	9	316409.80	4253218.72	90.04	67.40	0.68		0.106	49	46	0.951	
	MP Mag ACO	52	316409.72	4253218.25	89.96	66.93	0.79		0.111	55	38	0.964	
	MP EM GPS	11	316409.11	4253219.14	89.35	67.82	0.00	0.02	0.013				
	MP EM ACO	31	316410.17	4253218.65	90.41	67.33		0.09	0.033			0.389	
SEED T5	Ground Truth		316405.88	4253203.69			0.18		0.070	0	90		2.75 in WH, @ 1 ft.
2.75-in WH	Vehicle Mag EW	6	316405.96	4253203.77	86.20	52.45	0.30	0.05		59	29	0.962	
	Vehicle EM EW	5	316405.82	4253203.61	86.05	52.29		0.46	0.082			0.867	
	Fusion Fit	FUS-66	316405.96	4253203.73	86.19	52.41	0.30	0.26	0.047	70	37	0.980	
	MP Mag GPS	3	316405.86	4253203.82	86.10	52.50	0.26	0.05	0.067	70	25	1	
	MP Mag ACO	40	316405.57	4253203.42	85.81	52.10	0.29		0.044	62	48	0.971	
	MP EM GPS	7	316405.47	4253203.63	85.71	52.31		0.32	0.044			0.419	
	MP EM ACO	46	316405.88	4253203.17	86.11	51.85		0.21	0.046			0.579	

Table 5. Survey Analyses for the Seed Targets, Continued

Target ID	Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
SEED T6	Ground Truth		316413.91	4253207.02			0.18			0	45		60 mm Mortar, 30 deg nose down, 0.5 ft deep, under flag
M-23	Vehicle Mag EW	11	316413.98	4253206.99	94.22	55.67	0.24	0.06		42	325	0.946	
	Vehicle EM EW	9	316414.12	4253206.78	94.36	55.47		0.00	0.048			0.874	
	Vehicle EM EW	8	316414.08	4253206.82	94.32	55.50		0.01	0.052			0.836	
	Fusion Fit												
	MP Mag GPS	34	316413.94	4253206.98	94.17	55.66	0.23		0.054	46	345	0.912	
	MP Mag ACO	42	316413.62	4253206.58	93.85	55.26	0.20		0.047	42	339	0.921	
	MP EM GPS	9	316414.10	4253206.66	94.34	55.34	0.01	0.04	0.045				
	MP EM ACO	32	316414.79	4253206.43	95.03	55.11		0.00	0.035			0.543	
SEED T7	Ground Truth		316418.24	4253212.29			0.43		0.081	90	0		81 mm mortar, 0.75 ft deep, nose down to W, under flag
81 mm Mortar	Vehicle Mag EW	12	316418.19	4253212.26	98.43	60.94	0.53	0.10		76	290	0.941	
	Vehicle EM EW	11	316418.22	4253212.27	98.46	60.95		0.00	0.051			0.929	
	Fusion Fit												
	MP Mag GPS	35	316418.13	4253212.18	98.37	60.86	0.49		0.104	81	211	0.889	
	MP Mag ACO	51	316418.30	4253211.97	98.54	60.65	0.60		0.101	74	10	0.900	
	MP EM GPS	10	316418.30	4253212.17	98.54	60.85	0.00	0.04	0.052				
	MP EM ACO	28	316418.19	4253211.96	98.43	60.64		0.00	0.031			0.739	
SEED T8	Ground Truth		316422.59	4253210.13			0.43		0.081	0	0		81mm Mortar, nose down, 1.5 ft deep
81 mm Mortar	Vehicle Mag EW	13	316422.59	4253210.16	102.83	58.84	0.48	0.07		27	342	0.96	
	Vehicle EM EW	12	316422.70	4253209.94	102.94	58.62	0.72	0.12	0.334				
	Fusion Fit												
	MP Mag GPS	36	316422.58	4253210.04	102.82	58.72	0.43		0.070	22	350	0.901	
	MP Mag ACO	51	316418.30	4253211.97	98.54	60.65	0.60		0.101	74	10	0.915	
	MP EM GPS	12	316422.86	4253209.88	103.09	58.56	0.02	0.03	0.033				
	MP EM ACO	27	316422.51	4253209.96	102.75	58.64		0.00	0.018			0.397	
SEED T9	Ground Truth		316425.22	4253213.79			0.28		0.070	45	0		2.75 in WH, 1.0 ft deep, 45 deg
2.75 in WH	Vehicle Mag EW	14	316425.14	4253213.76	105.38	62.44	0.29	0.08		55	346	0.977	
	Vehicle EM EW	13	316425.32	4253213.57	105.55	62.25	0.00	0.05	0.080				
	Fusion Fit												
	MP Mag GPS	6	316425.19	4253213.71	105.43	62.39	0.28		0.084	50	349	0.921	
	MP Mag ACO	47	316422.31	4253209.59	102.54	58.27	0.47		0.066	32	343	0.961	
	MP Mag ACO	48	316425.31	4253213.31	105.55	61.99	0.32		0.086	66	349	0.961	
	MP EM GPS	13	316425.36	4253213.52	105.60	62.20	0.13	0.05	0.073				
	MP EM ACO	26	316425.30	4253213.10	105.53	61.78		0.00	0.034			0.515	
SEED T10	Ground Truth		316430.89	4253214.02			0.51		0.081	0	45		81mm Mortar @ 2.0 ft, pointing NE
81 mm Mortar	Vehicle Mag EW	15	316430.93	4253213.92	111.16	62.60	0.54	0.06		47	39	0.897	
	Vehicle EM EW	14	316430.92	4253213.95	111.15	62.63	0.98	0.12	0.322				
	Fusion Fit	FUS-68	316430.90	4253213.93	111.13	62.61	0.62	0.53	0.066	53	35	0.941	
	MP Mag GPS	7	316430.84	4253213.83	111.08	62.51	0.69		0.064	79	136	0.741	
	MP Mag ACO	46	316430.64	4253213.43	110.87	62.11	0.51		0.057	40	25	0.933	
	MP EM GPS	14	316430.61	4253213.87	110.84	62.55	0.21	0.04	0.058				
	MP EM ACO	25	316430.90	4253212.73	111.14	61.41		0.00	0.016			0.326	

Table 5. Survey Analyses for the Seed Targets, Continued

Target ID	Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
SEED T11	Ground Truth		316444.05	4253218.43			0.20			90	0		M 23 @0.5 ft,
M 23	Vehicle Mag EW	17	316443.97	4253218.43	124.21	67.11	0.17	0.06		82	144	0.979	
	Vehicle EM EW	16	316444.05	4253218.45	124.29	67.13	0.00	0.05	0.073				
	Fusion Fit	FUS-69	316443.97	4253218.43	124.20	67.11	0.18	0.16	0.063	84	147	0.983	
	MP Mag GPS	8	316444.15	4253218.51	124.38	67.19	0.13		0.063	90	270	0.978	
	MP Mag ACO	44	316443.85	4253217.59	124.09	66.28	0.20		0.057	77	135	0.797	
	MP EM GPS	16	316443.95	4253218.47	124.19	67.15	0.00	0.04	0.044				
	MP EM ACO	23	316443.44	4253217.63	123.68	66.31		0.00	0.038			0.762	
SEED T12	Ground Truth		316447.62	4253219.17			0.15			45	45		Mk23, 3 in deep, under flag
M 23	Vehicle Mag EW	18	316447.66	4253219.25	127.89	67.93	0.10	0.06		26	10	0.904	
	Vehicle EM EW	17	316447.70	4253218.80	127.93	67.48	0.00	0.03	0.034				
	Fusion Fit												
	MP Mag GPS	37	316447.58	4253219.08	127.82	67.76	0.07		0.050	58	37	0.898	
	MP Mag ACO	43	316447.49	4253218.23	127.73	66.91	0.16		0.057	23	22	0.913	
	MP EM GPS	17	316447.74	4253219.01	127.97	67.69	0.00	0.04	0.045				
	MP EM ACO	22	316447.85	4253218.59	128.09	67.27		0.00	0.022			0.662	
SEED T13	Ground Truth		316466.66	4253176.38			0.30		0.070	90	0		2.75 in WH, nose down, 12 in to tail, Flag 2 in N, 26 in E
2.75 in WH	MP Mag ACO	6	316466.34	4253176.03	146.57	24.71	0.46		0.096	90	275	0.717	
	MP EM ACO	61	316467.15	4253176.53	147.39	25.21		0.00	0.024			0.674	
SEED T14	Ground Truth		316459.80	4253190.89			0.30		0.070	0	90		
2.75 in WH													
	MP Mag ACO	38	316459.43	4253191.01	139.66	39.69	0.43		0.055	34	19	0.732	
	MP EM ACO												
SEED T15	Ground Truth		316447.14	4253189.47			0.15			0	0		Mk23, 7 in deep, Flag 18 in N, 12 in
M 23	MP Mag ACO	2	316447.34	4253189.83	127.57	38.51	0.68		0.074	59	20	0.875	
	MP EM ACO	60	316446.98	4253189.77	127.22	38.45		0.00	0.023			0.552	
SEED T16	Ground Truth		316442.15	4253176.94			0.15			0	45		Mk23, , nose down, 11 in deep,
M 23	MP Mag ACO	3	316442.26	4253176.80	122.50	25.48	0.37		0.049	39	20	0.882	
	MP EM ACO		316443.34	4253176.90	123.58	25.58		0.00	0.020			0.700	
SEED T17	Ground Truth		316430.48	4253175.41			0.30		0.060	45	0		60mm Mortar, 45 deg nose down, 6 in to tail, Flag 13 in N
60 mm Mortar	MP Mag ACO	4	316430.60	4253175.47	110.84	24.15	0.34		0.052	40	317	0.896	
	MP EM ACO	56	316430.18	4253174.27	110.42	22.95		0.00	0.028			0.251	
SEED T18	Ground Truth		316428.52	4253167.26			0.48		0.081	45	45		81mm Mortar, 45 deg nose down, 14 in to tail, Flag 30 in N, 20 in E
81mm Mortar	MP Mag ACO	5	316428.64	4253167.30	108.88	15.98	0.67		0.084	51	25	0.910	
	MP EM ACO	55	316428.83	4253167.67	109.07	16.35		0.00	0.017			0.305	

Table 6. Survey Analysis of Man-Portable Targets in the GPS-Accessible Area

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													25lb Frag Bomb @12 in.nose down 45 deg
Vehicle Mag EW	7	316406.09	4253207.32	86.32	56.00	0.31	0.10		0.5535	67	323	0.932	
Vehicle EM EW	6	316406.20	4253207.13	86.44	55.81		0.00	0.058				0.949	
Fusion Fit	FUS-65	316406.09	4253207.32	86.33	56.00	0.31	0.29	0.101	0.5590	68	324	0.932	
MP Mag GPS	4	316406.01	4253207.35	86.24	56.03	0.26		0.098	0.5033	52	342	0.878	
MP Mag ACO	41	316405.93	4253207.09	86.17	55.77	0.36		0.103	0.6018	65	358	0.883	
MP EM GPS	8	316406.33	4253207.19	86.57	55.87		0.06	0.062				0.892	
MP EM ACO	45	316406.21	4253206.95	86.45	55.63		0.30	0.057				0.860	
Ground Truth													81 mm Mortar, unfuzed
Vehicle Mag EW	26	316394.27	4253221.68	74.51	70.36	0.20	0.06		0.1336	47	301	0.941	
Vehicle EM EW	3	316394.32	4253221.68	74.56	70.36		0.42	0.106				0.804	
Fusion Fit	FUS-156	316394.30	4253221.68	74.53	70.36	0.21	0.23	0.062	0.1320	51	309	0.953	
MP Mag GPS	10	316394.32	4253221.23	74.56	69.91	0.14		0.063	0.1379	80	202	0.836	
MP Mag ACO	58	316394.59	4253221.22	74.82	69.90	0.21		0.057	0.0999	49	323	0.931	
MP EM GPS	23	316394.25	4253221.59	74.49	70.27		0.23	0.066				0.591	
MP EM ACO	38	316394.14	4253221.02	74.38	69.71		0.02	0.045				0.748	
Ground Truth													81 mm Mortar, illumination,dirt filled, near surface
Vehicle Mag EW	23	316398.53	4253222.35	78.77	71.03	0.09	0.07		0.2058	26	1	0.894	
Vehicle EM EW	5	316398.70	4253222.46	78.94	71.14		0.08	0.092				0.92	
Fusion Fit	FUS-154	316398.54	4253222.35	78.77	71.03	0.10	0.01	0.074	0.2240	26	2	0.907	
MP Mag GPS	11	316398.79	4253222.19	79.02	70.87	0.11		0.063	0.1351	78	125	0.96	
MP Mag ACO	56	316398.57	4253221.92	78.81	70.60	0.16		0.069	0.1786	43	3	0.918	
MP EM GPS	19	316399.39	4253222.75	79.63	71.43		0.00	0.031				0.176	
MP EM ACO	36	316399.07	4253222.03	79.31	70.71		0.07	0.062				0.648	
Ground Truth													81mm Mortar, 3 in deep, 6 in S of Flag
Vehicle Mag EW	27	316388.62	4253223.02	68.86	71.70	0.14	0.07		0.1552	40	30	0.944	
Vehicle EM EW	2	316388.67	4253222.97	68.90	71.65		0.00	0.061				0.922	
Fusion Fit	FUS-71	316388.62	4253223.02	68.85	71.70	0.14	0.10	0.066	0.1550	40	29	0.944	
MP Mag GPS	12	316388.50	4253222.96	68.74	71.64	0.19		0.069	0.1814	49	41	0.715	
MP Mag ACO	59	316388.99	4253222.64	69.22	71.32	0.18		0.066	0.1529	43	50	0.946	
MP EM GPS	24	316388.50	4253222.89	68.73	71.57		0.12	0.064				0.84	
MP EM ACO	39	316388.79	4253222.35	69.03	71.03		0.11	0.059				0.919	
Ground Truth													81mm Mortar, split in half, 0.25 ft deep
Vehicle Mag EW	25	316395.94	4253223.81	76.18	72.49	0.10	0.05		0.0517	31	25	0.97	
Vehicle EM EW	4	316395.85	4253223.81	76.08	72.49		0.00	0.035				0.761	
Fusion Fit	FUS-157	316395.95	4253223.81	76.18	72.49	0.09	0.12	0.045	0.0490	32	27	0.977	
MP Mag GPS	13	316396.00	4253223.88	76.23	72.56	0.04		0.035	0.0235	47	21	0.681	
MP Mag ACO	57	316396.24	4253223.61	76.48	72.29	0.10		0.040	0.0358	28	19	0.895	
MP EM GPS	22	316395.81	4253223.78	76.05	72.46		0.25	0.062				0.632	
MP EM ACO	37	316396.12	4253223.37	76.36	72.05		0.14	0.056				0.766	

Table 6. Survey Analysis of Man-Portable Targets in the GPS-Accessible Area

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													81 mm Mortar at 0.75 ft, scrap above on surface
Vehicle Mag EW	21	316412.64	4253224.25	92.88	72.93	0.24	0.08		0.2837	24	65	0.833	
Vehicle EM EW	10	316412.57	4253224.01	92.81	72.69		0.27	0.076				0.833	
Fusion Fit	FUS-153	316412.64	4253224.25	92.88	72.93	0.22	0.29	0.078	0.2570	24	69	0.829	
MP Mag GPS	14	316412.50	4253224.10	92.74	72.78	0.12		0.070	0.1870	15	53	0.842	
MP Mag ACO	53	316412.57	4253223.75	92.80	72.43	0.23		0.076	0.2402	22	57	0.878	
MP EM GPS	21	316412.20	4253224.04	92.44	72.72		0.48	0.072				0.847	
MP EM ACO	30	316413.07	4253223.51	93.31	72.19		0.11	0.045				0.689	
Ground Truth													81 mm Mortar at 0.5 ft, nose down
Vehicle Mag EW	24	316400.79	4253227.50	81.02	76.18	0.18	0.08		0.3147	59	44	0.942	
Vehicle EM EW	9	316400.78	4253227.55	81.01	76.23		0.21	0.088				0.572	
Fusion Fit	FUS-155	316400.79	4253227.38	81.02	76.06	0.19	0.19	0.083	0.3150	63	116	0.943	
MP Mag GPS	15	316401.04	4253227.52	81.27	76.20	0.20		0.090	0.3982	57	76	0.842	
MP Mag ACO	60	316401.13	4253227.06	81.36	75.74	0.26		0.091	0.4157	58	47	0.958	
MP EM GPS	20	316401.00	4253227.65	81.24	76.33		0.03	0.053				0.824	
MP EM ACO	35	316401.02	4253226.79	81.26	75.47		0.00	0.048				0.909	
Ground Truth													2 ft long, 1/4 in wire at 0.5 ft.
Vehicle Mag EW	19	316433.02	4253229.62	113.26	78.30	0.17	0.06		0.1164	25	41	0.864	
Vehicle EM EW	11	316433.65	4253229.80	113.89	78.48		0.00	0.025				0.564	
Fusion Fit	FUS-121	316433.03	4253229.63	113.27	78.31	0.17	0.27	0.061	0.1220	23	43	0.877	
MP Mag GPS	16	316432.78	4253229.59	113.02	78.27	0.16		0.062	0.1302	25	45	0.826	
MP Mag ACO	49	316432.97	4253228.76	113.21	77.44	0.25		0.062	0.1277	27	38	0.747	
MP EM GPS	18	316432.19	4253228.29	112.41	76.97		0.10	0.027				0.410	
MP EM ACO	21	316433.37	4253229.06	113.61	77.74		0.00	0.020				0.446	
Ground Truth													OE Frag, 2 in X 1 in X 1/8 in, 6 in deep, Under Flag
Vehicle Mag EW	20	316431.77	4253227.88	112.01	76.56	0.22	0.09		0.3346	15	9	0.937	
Vehicle EM EW													
Fusion Fit													
MP Mag GPS	17	316431.87	4253227.93	112.11	76.61	0.16		0.087	0.3516	22	18	0.893	
MP Mag ACO	50	316431.99	4253226.95	112.22	75.63	0.19		0.086	0.3477	16	359	0.926	
MP EM GPS	18	316432.19	4253228.29	112.42	76.97		0.10	0.027				0.412	
MP EM ACO	20	316431.57	4253226.39	111.81	75.07		0.00	0.017				0.263	
Ground Truth													81mm Mortar at 0.25 ft, deep, 12 in E of flag
Vehicle Mag EW	28	316396.23	4253236.00	76.47	84.68	0.45	0.15		1.7020	10	270	0.66	
Vehicle EM EW	8	316397.41	4253236.02	77.65	84.70		0.21	0.102				0.934	
Fusion Fit	FUS-185	316397.18	4253236.04	77.42	84.72	0.45	0.20	0.121	0.9550	35	14	0.763	
MP Mag GPS	18	316396.38	4253236.08	76.62	84.76	0.30		0.119	0.9063	10	278	0.607	
MP Mag ACO	68	316396.32	4253236.02	76.55	84.70	0.42		0.129	1.1608	19	267	0.630	
MP EM GPS	25	316397.48	4253236.09	77.72	84.77		0.00	0.076				0.932	
MP EM ACO	13	316397.39	4253236.06	77.62	84.74		0.13	0.079				0.915	

Table 6. Survey Analysis of Man-Portable Targets in the GPS-Accessible Area

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													2 in angle iron, 4 ft long, at surface
Vehicle Mag EW	30	316390.56	4253236.64	70.80	85.32	0.00	0.12		0.9481	-39	91	0.395	
Vehicle EM EW	6	316390.77	4253236.90	71.00	85.58		0.45	0.216				0.764	
Fusion Fit	FUS-183	316390.88	4253236.94	71.12	85.62	0.37	0.36	0.270	10.7040	-6	33	0.846	
MP Mag GPS	19	316390.64	4253236.94	70.88	85.62	0.37		0.262	9.7758	-23	39	0.904	
MP Mag ACO	67	316390.85	4253236.93	71.08	85.61	0.35		0.247	8.1298	12	39	0.917	
MP EM GPS	27	316390.95	4253236.87	71.18	85.65		0.29					0.820	
MP EM ACO	12	316391.07	4253237.22	71.30	85.90		0.39	0.150				0.600	
Ground Truth													2 pieces of frag , 5 in deep, 10 in E & W of Flag
Vehicle Mag EW	29	316395.68	4253237.46	75.91	86.14	0.48	0.13		1.1613	54	117	0.851	
Vehicle EM EW	7	316395.18	4253237.89	75.41	86.57		0.58	0.101				0.876	
Fusion Fit	FUS-184	316395.68	4253237.49	75.91	86.17	0.40	0.68	0.115	0.8300	59	107	0.888	
MP Mag GPS	20	316395.38	4253237.48	75.62	86.16	0.34		0.117	0.8583	42	78	0.762	
MP Mag ACO	69	316395.73	4253237.47	75.96	86.15	0.55		0.135	1.3463	50	114	0.887	
MP EM GPS	27	316390.95	4253236.97	71.18	85.65		0.29	0.139				0.82	
MP EM GPS	26	316395.23	4253237.81	75.46	86.49		0.73	0.092				0.579	
MP EM ACO	10	316395.24	4253237.89	75.48	86.57		0.68	0.086				0.411	
Ground Truth													81 mm Mortar, nose down at 0.25 ft
Vehicle Mag EW	46	316428.48	4253240.07	108.72	88.75	0.19	0.07		0.1557	31	10	0.895	
Vehicle EM EW	12	316428.62	4253240.16	108.85	88.84		0.15	0.079				0.91	
Fusion Fit	FUS-122	316428.49	4253240.06	108.73	88.75	0.18	0.15	0.064	0.1420	34	15	0.894	
MP Mag GPS	21	316428.48	4253240.09	108.72	88.77	0.26		0.072	0.1991	45	342	0.778	
MP Mag ACO	73	316428.37	4253240.04	108.60	88.72	0.23		0.063	0.1385	33	19	0.927	
MP EM GPS	37	316428.70	4253240.27	108.94	88.95		0.00	0.042				0.634	
MP EM ACO	19	316428.82	4253239.38	109.05	88.06		0.24	0.070				0.800	
Ground Truth													Rocket, 5 in diam, 64 in long, at 3.26 ft, pointing E/W
Vehicle Mag EW	33	316386.59	4253242.34	66.83	91.02	0.17	0.07		0.1601	6	317	0.935	
Vehicle EM EW													
Fusion Fit	FUS-181	316387.22	4253240.25	67.45	88.93	1.17	1.17	0.180	3.1570	81	75	0.948	
MP Mag GPS	22	316386.36	4253241.72	66.59	90.40	0.27		0.068	0.1708	0	310	0.866	
MP Mag ACO	66	316386.57	4253242.43	66.80	91.11	0.22		0.064	0.1403	11	309	0.823	
MP EM GPS													
MP EM ACO	11	316387.03	4253243.05	67.27	91.73		0.00	0.019				0.633	
Ground Truth													2 pieces of OE Scrap, 4 & 2 in long @ 4 in deep
Vehicle Mag EW	45	316425.45	4253241.60	105.68	90.28	0.08	0.11		0.6931	2	66	0.975	
Vehicle EM EW	13	316424.88	4253241.62	105.12	90.30		0.00	0.048				0.934	
Fusion Fit	FUS-152	316425.45	4253241.60	105.68	90.28	0.08	0.05	0.108	0.6880	2	66	0.974	
MP Mag GPS	23	316425.27	4253241.61	105.50	90.29	0.11		0.100	0.5507	8	74	0.681	
MP Mag ACO	74	316425.42	4253241.48	105.66	90.16	0.13		0.099	0.5207	1	72	0.867	
MP EM GPS	36	316424.85	4253241.67	105.08	90.35		0.03	0.048				0.818	
MP EM ACO	18	316424.51	4253242.14	104.74	90.82		0.00	0.037				0.611	

Table 6. Survey Analysis of Man-Portable Targets in the GPS-Accessible Area

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													1 in X 2 in strap with bolt near surface, not OE
Vehicle Mag EW	34	316389.26	4253246.00	69.50	94.68	0.06	0.05		0.0783	25	67	0.984	
Vehicle EM EW	21	316389.14	4253245.86	69.38	94.54		0.22	0.071				0.696	
Fusion Fit	FUS-51	316389.26	4253245.99	69.50	94.68	0.06	0.08	0.052	0.0780	26	68	0.989	
MP Mag GPS	24	316389.28	4253245.99	69.51	94.67	0.12		0.054	0.0835	30	62	0.891	
MP Mag ACO	70	316389.21	4253246.09	69.45	94.77	0.13		0.055	0.0923	35	56	0.837	
MP EM GPS	29	316389.06	4253245.89	69.30	94.57		0.41	0.070				0.759	
MP EM ACO	9	316388.71	4253245.96	68.94	94.64		0.51	0.074				0.691	
Ground Truth													81 mm Mortar, split in half, 1 in deep
Vehicle Mag EW	42	316417.39	4253246.01	97.63	94.69	0.08	0.07		0.1700	19	22	0.899	
Vehicle EM EW	15	316417.37	4253246.12	97.61	94.80		0.01	0.066				0.945	
Fusion Fit	FUS-151	316417.39	4253246.02	97.63	94.70	0.02	0.07	0.057	0.0980	21	21	0.850	
MP Mag GPS	25	316417.05	4253245.73	97.28	94.41	0.07		0.100	0.5383	61	50	0.895	
MP Mag ACO	75	316417.53	4253246.04	97.77	94.73	0.16		0.077	0.2431	22	18	0.953	
MP EM GPS													
MP EM ACO	14	316417.33	4253246.19	97.57	94.87		0.21	0.070				0.820	
Ground Truth													OE Frag, 3 in X 0.5 in, near surface
Vehicle Mag EW	44	316431.40	4253251.50	111.63	100.18	0.08	0.08		0.2659	1	20	0.931	
Vehicle EM EW	14	316431.25	4253251.74	111.49	100.42		0.00	0.030				0.787	
Fusion Fit	FUS-123	316431.43	4253251.51	111.67	100.19	0.11	0.13	0.087	0.3550	-1	25	0.902	
MP Mag GPS	26	316431.77	4253251.60	112.01	100.28	0.00		0.060	0.1170	-4	24	0.712	
MP Mag ACO	78	316431.69	4253251.48	111.93	100.16	0.12		0.070	0.1887	-9	20	0.903	
MP EM GPS	39	316430.98	4253251.32	111.21	100.00		0.00	0.010				0.120	
MP EM ACO	17	316431.12	4253251.86	111.36	100.54		0.00	0.022				0.378	
Ground Truth													81mm Mortar, nose down, 21 in deep to center
Vehicle Mag EW	40	316414.47	4253253.56	94.71	102.24	0.61	0.09		0.3554	85	80	0.97	
Vehicle EM EW	17	316414.36	4253253.64	94.60	102.32		0.05	0.050				0.939	
Fusion Fit	FUS-32	316414.50	4253253.54	94.74	102.22	0.66	0.36	0.091	0.4140	82	108	0.981	
MP Mag GPS	27	316414.22	4253252.81	94.45	101.49	0.74		0.093	0.4380	76	188	0.879	
MP Mag ACO	77	316414.74	4253253.69	94.98	102.37	0.70		0.093	0.4300	90	105	0.926	
MP EM GPS	33	316414.49	4253253.44	94.73	102.12		0.25	0.046				0.708	
MP EM ACO	15	316414.25	4253253.51	94.49	102.19		0.26	0.049				0.793	
Ground Truth													3 in (71mm) Mortar, no fuze, at 0.25 ft deep, flat EW under Flag
Vehicle Mag EW	43	316422.56	4253257.13	102.79	105.81	0.17	0.06		0.1179	39	255	0.838	
Vehicle EM EW	16	316422.43	4253257.05	102.66	105.73		0.00	0.047				0.757	
Fusion Fit	FUS-31	316422.55	4253257.12	102.79	105.80	0.16	0.07	0.060	0.1180	38	254	0.837	
MP Mag GPS	28	316422.63	4253257.21	102.87	105.89	0.23		0.074	0.2199	26	251	0.85	
MP Mag ACO	79	316422.70	4253257.36	102.94	106.04	0.19		0.054	0.0838	38	258	0.677	
MP EM GPS	35	316422.31	4253256.99	102.55	105.67		0.08	0.058				0.865	
MP EM ACO	5	316422.09	4253257.02	102.33	105.70		0.12	0.062				0.843	

Table 6. Survey Analysis of Man-Portable Targets in the GPS-Accessible Area

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													OE Frag, 3 in X 1 in X 1/8 in
Vehicle Mag EW	38	316402.11	4253260.80	82.35	109.48	0.11	0.06		0.1114	17	132	0.957	
Vehicle EM EW	19	316401.81	4253261.10	82.05	109.78		0.00	0.028				0.764	
Fusion Fit	FUS-34	316402.11	4253260.81	82.35	109.49	0.11	0.17	0.059	0.1090	17	132	0.948	
MP Mag GPS	29	316402.23	4253260.78	82.47	109.46	0.17		0.059	0.1131	22	145	0.946	
MP Mag ACO	85	316402.52	4253260.89	82.76	109.57	0.17		0.061	0.1228	21	140	0.964	
MP EM GPS	31	316401.59	4253260.77	81.82	109.45		0.00	0.017				0.681	
MP EM ACO	6	316401.29	4253260.70	81.52	109.38		0.00	0.017				0.659	
Ground Truth													4.2 in Stokes, broken in half @ 1 ft deep, 8 in long
Vehicle Mag EW	39	316416.87	4253261.01	97.11	109.69	0.34	0.08		0.3000	23	39	0.896	
Vehicle EM EW	18	316416.86	4253261.01	97.10	109.70		0.25	0.074				0.935	
Fusion Fit	FUS-150	316416.88	4253261.01	97.11	109.69	0.29	0.34	0.075	0.2260	24	40	0.875	
MP Mag GPS	30	316416.95	4253261.00	97.19	109.68	0.39		0.083	0.3154	29	42	0.921	
MP Mag ACO	87	316417.20	4253261.03	97.43	109.71	0.37		0.800	0.2778	27	63	0.870	
MP EM GPS	34	316416.97	4253261.03	97.21	109.71		0.15	0.050				0.796	
MP EM ACO	4	316416.48	4253260.89	96.72	109.57		0.14	0.048				0.815	
Ground Truth													OE Frag, 1 in X 1.5 in X 1/8 in at 0.75 ft deep
Vehicle Mag EW	49	316412.21	4253268.22	92.45	116.90	0.16	0.08		0.2430	12	301	0.912	
Vehicle EM EW													
Fusion Fit	FUS-149	316414.89	4253267.14	95.12	115.82	0.20	0.14	0.049	0.0660	-21	90	0.800	
MP Mag GPS	31	316412.15	4253268.26	92.39	116.94	0.16		0.069	0.1759	12	298	0.875	
MP Mag ACO	83	316412.37	4253268.37	92.61	117.05	0.39		0.089	0.3819	30	294	0.518	
MP EM GPS													
MP EM ACO	67	316414.41	4253267.13	94.65	115.81		0.00	0.030					
Ground Truth													3 pieces of OE Scrap, tail fins, 81mm Tail boom, 105mm WH
Vehicle Mag EW	50	316410.99	4253268.86	91.22	117.54	0.72	0.13		1.0882	71	175	0.963	
Vehicle EM EW	24	316410.93	4253269.01	91.17	117.69		0.51	0.094				0.966	
Fusion Fit	FUS-148	316411.05	4253268.89	91.29	117.57	0.75	0.98	0.130	1.1870	71	139	0.968	
MP Mag GPS	32	316411.26	4253268.86	91.50	117.54	0.86		0.154	1.9919	37	116	0.941	
MP Mag ACO	84	316411.20	4253268.87	91.44	117.55	0.68		0.119	0.9218	58	143	0.910	
MP EM GPS	38	316410.93	4253269.05	91.16	117.73		0.96	0.115				0.531	
MP EM ACO	3	316410.64	4253268.92	90.88	117.60		0.90	0.118				0.719	
Ground Truth													2 in angle iron, 11 in long, bent, 0.25 ft deep
Vehicle Mag EW	51	316413.89	4253271.45	94.13	120.13	0.13	0.07		0.1689	9	166	0.783	
Vehicle EM EW	23	316414.72	4253271.19	94.96	119.87		0.12	0.056				0.925	
Fusion Fit	FUS-49	316393.27	4253271.72	73.51	120.40	0.07	0.06	0.048	0.0610	32	337	0.988	
MP Mag GPS	33	316413.94	4253271.42	94.18	120.10	0.08		0.059	0.1122	-9	157	0.846	
MP Mag ACO	82	316414.10	4253271.63	94.33	120.31	0.16		0.064	0.1403	-3	162	0.819	
MP EM GPS													
MP EM ACO	2	316414.74	4253270.88	94.97	119.56		0.16	0.037				0.745	

Table 6. Survey Analysis of Man-Portable Targets in the GPS-Accessible Area

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													81 mm Mortar, nose down, 1.5 ft to base, under the flag
Vehicle Mag EW	16	316441.44	4253217.02	121.67	65.70	0.73	0.10		0.4670	87	191	0.927	
Vehicle EM EW	15	316441.31	4253217.11	121.54	65.79		0.50	0.095				0.637	
Fusion Fit													
MP Mag GPS	38	316441.34	4253216.95	121.58	65.63	0.70		0.093	0.4326	87	90	0.903	
MP Mag ACO	45	316441.30	4253216.34	121.54	65.02	0.70		0.086	0.3506	79	45	0.876	
MP EM GPS	15	316441.71	4253216.82	121.95	65.50		0.00	0.020				0.69	
MP EM ACO	24	316440.34	4253216.96	120.58	65.64		0.08	0.038				0.727	
Ground Truth													OE Frag, 3 in X 2.5 in X 1/ in,4 in deep, under flag
Vehicle Mag EW	8	316402.36	4253211.29	82.59	59.97	0.14	0.09		0.3878	7	72	0.826	
Vehicle Mag EW	9	316402.36	4253211.29	82.59	59.97	0.14	0.09		0.3931	7	72	0.827	
Vehicle EM EW	7	316402.01	4253211.22	82.25	59.90		0.00	0.011				0.078	
Fusion Fit													
MP Mag GPS	39	316402.35	4253211.38	82.59	60.06	0.11		0.089	0.3856	10	62	0.973	
MP Mag ACO	54	316402.28	4253210.93	82.52	59.61	0.17		0.088	0.3723	9	62	0.979	
MP EM GPS	6	316402.55	4253211.95	82.78	60.63		0.08	0.030				0.49	
MP EM ACO	33	316402.29	4253211.04	82.52	59.72		0.40	0.046				0.452	
Ground Truth													81 mm flat EW, 1.5 ft deep, under the flag
Vehicle Mag EW													
Vehicle EM EW	3	316381.90	4253210.97	62.14	59.65		0.01	0.047				0.953	
Vehicle EM EW	4	316381.84	4253211.01	62.08	59.69	0.87	0.10		0.5837	77	356	0.923	
Fusion Fit													
MP Mag GPS	40	316381.85	4253211.04	62.09	59.72	0.62		0.088	0.3670	70	336	0.948	
MP Mag ACO	61	316381.87	4253210.69	62.11	59.38	0.69		0.087	0.3547	89	90	0.958	
MP EM GPS	4	316381.96	4253211.34	62.19	60.02		0.32	0.051				0.684	
MP EM ACO	40	316382.22	4253210.90	62.46	59.58		0.42	0.055				0.618	
Ground Truth													81mm, nose down, 27 in deep, Flag 12 in E, 17 in W
Vehicle Mag EW	3	316370.13	4253210.71	50.37	59.39	0.71	0.08		0.2870	52	319	0.896	
Vehicle EM EW													
Fusion Fit													
MP Mag GPS	41	316370.28	4253210.62	50.51	59.30	0.84		0.090	0.3960	67	333	0.854	
MP Mag ACO	64	316370.33	4253210.46	50.57	59.14	0.74		0.075	0.2332	89	90	0.809	
MP EM GPS	3	316370.12	4253210.70	50.35	59.38		0.39	0.052				0.799	
MP EM ACO	42	316370.57	4253209.86	50.81	58.54		0.39	0.052				0.615	
Ground Truth													81 mm Mortar, nose down, 1.5 ft deep, under the flag
Vehicle Mag EW	31	316375.36	4253221.62	55.60	70.30	0.57	0.09		0.3529	86	340	0.93	
Vehicle EM EW	1	316375.28	4253221.65	55.52	70.33		0.00	0.048				0.859	
Fusion Fit													
MP Mag GPS	42	316375.30	4253221.64	55.54	70.32	0.56		0.088	0.3714	85	336	0.93	
MP Mag ACO	62	316375.22	4253221.39	55.46	70.07	0.94		0.117	0.8703	70	304	0.767	
MP EM GPS	28	316375.07	4253221.33	55.30	70.01		0.00	0.028				0.543	
MP EM ACO	41	316375.84	4253220.85	56.08	69.53		0.30	0.057				0.859	

Table 6. Survey Analysis of Man-Portable Targets in the GPS-Accessible Area

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													OE Scrap, 2 in X 1 in, 4 in deep, under the flag
Vehicle Mag EW													
Vehicle EM EW													
Fusion Fit													
MP Mag GPS	43	316417.15	4253221.12	97.39	69.80	0.10		0.069	0.1763	13	352	0.966	
MP Mag ACO	88	316412.22	4253220.57	97.45	69.25	0.17		0.070	0.1879	19	3	0.936	
MP EM GPS													
MP EM ACO	29	316416.44	4253221.95	96.67	70.63		0.85	0.105				0.542	
Ground Truth													OE Scrap, 3 in diam, 5 in deep, Flag 21 in S, 18 in W
Vehicle Mag EW	41	316413.58	4253250.43	93.81	99.11	0.10	0.09		0.3314	-4	304	0.989	
Vehicle EM EW													
Fusion Fit													
MP Mag GPS	44	316413.48	4253249.80	93.71	98.48	0.16		0.087	0.3592	-5	309	0.989	
MP Mag ACO	76	316413.92	4253250.62	94.16	99.30	0.16		0.086	0.3459	-7	303	0.988	
MP EM GPS													
MP EM ACO													
Ground Truth													Frag 3 in flat, 0.75 in deep, Flag 18 in S, 15in W
Vehicle Mag EW	37	316405.75	4253245.69	85.99	94.37	0.21	0.10		0.4843	50	63	0.986	
Vehicle EM EW	22	316405.53	4253245.58	85.77	94.26		0.00	0.019				0.594	
Fusion Fit													
MP Mag GPS	45	316405.72	4253245.07	85.96	93.75	0.27		0.096	0.4862	50	61	0.957	
MP Mag ACO	71	316405.87	4253245.69	86.11	94.37	0.27		0.098	0.5052	50	66	0.978	
MP EM GPS													
MP EM ACO	16	316405.37	4253245.43	85.60	94.11		0.00	0.018				0.358	
Ground Truth													Frag 6 in X 1 in X 1/4 in, 6 in deep, Flag 18 in S, 21 in W
Vehicle Mag EW													
Vehicle EM EW	36	316403.89	4253248.75	84.12	97.43	0.17	0.08		0.2279	12	40	0.98	
Fusion Fit													
MP Mag GPS	46	316403.67	4253248.06	83.91	96.74	0.29		0.078	0.2613	16	41	0.741	
MP Mag ACO	72	316404.26	4253248.82	84.50	97.50	0.19		0.071	0.1920	17	41	0.942	
MP EM GPS													
MP EM ACO													
Ground Truth													Frag, 1 in X 2.5 in X 1/8 in, 6 in deep, Flag 12 in E
Vehicle Mag EW	32	316377.46	4253229.98	57.70	78.66	0.20	0.08		0.2766	7	339	0.945	
Vehicle EM EW													
Fusion Fit													
MP Mag GPS	47	316377.56	4253229.96	57.79	78.64	0.20		0.074	0.2177	28	349	0.977	
MP Mag ACO	63	316377.42	4253229.95	57.66	78.63	0.24		0.078	0.2605	8	340	0.971	
MP EM GPS													
MP EM ACO													

Table 6. Survey Analysis of Man-Portable Targets in the GPS-Accessible Area

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													
Vehicle Mag EW	35	316384.88	4253252.55	65.12	101.23	0.15	0.10		0.6120	21	28	0.929	
Vehicle EM EW													
Fusion Fit													
MP Mag GPS	48	316384.82	4253252.54	65.06	101.22	0.21		0.103	0.5883	17	40	0.887	
MP Mag ACO	65	316384.89	4253252.62	65.13	101.30	0.19		0.102	0.5783	18	40	0.965	
MP EM GPS													
MP EM ACO	8	316384.48	4253252.44	64.72	101.12		0.00	0.013				0.503	
Ground Truth													? 1.25 ft long, flat, 9 in deep, under the flag
Vehicle Mag EW	52	316393.80	4253261.67	74.04	110.35	0.23	0.09		0.4171	10	293	0.942	
Vehicle EM EW	20	316394.30	4253261.37	74.54	110.05		0.00	0.047				0.561	
Fusion Fit													
MP Mag GPS	49	316393.88	4253261.69	74.12	110.37	0.25		0.088	0.3674	7	301	0.98	
MP Mag ACO	86	316394.04	4253261.84	74.27	110.52	0.28		0.090	0.3953	13	289	0.940	
MP EM GPS	30	316393.72	4253261.36	73.96	110.04		0.29	0.057				0.641	
MP EM ACO	7	316394.47	4253261.53	74.71	110.21		0.00	0.027				0.809	
Ground Truth													Frag, 3 in diameter, 0.5 ft deep, under the flag
Vehicle Mag EW	47	316421.65	4253267.04	101.89	115.72	0.17	0.09		0.3848	-7	44	0.867	
Vehicle EM EW													
Fusion Fit													
MP Mag GPS	50	316421.66	4253266.99	101.90	115.67	0.18		0.083	0.3086	-1	45	0.965	
MP Mag ACO	80	316422.24	4253267.13	102.47	115.81	0.14		0.078	0.2608	-3	35	0.756	
MP EM GPS													
MP EM ACO													
Ground Truth													Frag, 3 in X 1 in X 1/4 in, 6 in deep, under the flag
Vehicle Mag EW	48	316421.96	4253272.27	102.20	120.96	0.19	0.07		0.1803	69	323	0.879	
Vehicle EM EW	25	316422.03	4253271.96	102.26	120.64		0.00	0.015				0.208	
Fusion Fit													
MP Mag GPS	51	316421.96	4253272.26	102.20	120.95	0.17		0.063	0.1369	67	336	0.985	
MP Mag ACO	81	316422.28	4253272.47	102.51	121.15	0.24		0.083	0.3092	74	359	0.836	
MP EM GPS													
MP EM ACO	1	316421.95	4253272.46	102.19	121.14		0.00	0.012				0.519	

Table 7. Survey Analysis of the Man-Portable Targets in the Woods

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													OE Scrap 3 in X 1 in X 1/8 in, Flag 3 in N, 4 in W
MP Mag ACO	1	316458.09	4253192.03	138.33	40.71	0.22		0.074	0.2188	12	193	0.823	
MP EM ACO													
Ground Truth													OE Scrap, 3.5 in X ?, 0.5 ft deep
MP Mag ACO	7	316436.85	4253207.23	117.09	55.91	0.21		0.088	0.3735	-10	301	0.912	
MP EM ACO	48	316436.28	4253206.59	116.51	55.27		0.15	0.036				0.270	
Ground Truth													OE Frag, 4 in X 1.5 in., 3 in deep, Flat, Under Flag
MP Mag ACO	8	316446.77	4253204.74	127.01	53.42	0.37		0.103	0.5877	87	96	0.891	
MP EM ACO	62	316446.57	4253203.70	126.81	52.38		0.00	0.044				0.077	
Ground Truth													OE Frag, very Hot, 12 in deep, Flag 4 in S, 7 in E
MP Mag ACO	9	316440.54	4253198.02	120.77	46.70	1.16		0.101	0.5597	39	116	0.872	
MP EM ACO													
Ground Truth													OE Frag, 5 in Flat, 5 in deep, Flag 2 in N, 10 in E
MP Mag ACO	10	316439.06	4253177.94	119.29	26.62	0.11		0.103	0.5959	-10	317	0.859	
MP EM ACO	58	316439.38	4253177.55	119.62	26.23		0.00	0.016					
Ground Truth													OE Frag, Flat Chunk, 7 in deep, Flag 8 in S, 12 iun W
MP Mag ACO	11	316424.83	4253189.47	105.06	38.15	0.10		0.070	0.1884	13	288	0.846	
MP EM ACO													
Ground Truth													OE Scrap, 1 in X 2.5 in X 1/8 in, 6 in deep, Under Flag
MP Mag ACO	12	316416.72	4253186.35	96.96	35.03	0.18		0.069	0.1806	13	72	0.850	
MP EM ACO													
Ground Truth													OE Scrap, 4 in size, 4 in deep, 12 in E of Flag
MP Mag ACO	13	316413.31	4253198.56	93.55	47.24	0.14		0.089	0.3809	0	323	0.978	
MP EM ACO	50	316413.35	4253198.53	93.59	47.21		0.24	0.040				0.563	
Ground Truth													OE Scrap, 4 in strip, 6 in deep, 30 in S of flag
MP Mag ACO	14	316367.55	4253177.55	47.79	26.23	0.24		0.077	0.2439	-7	96	0.865	
MP EM ACO	54	316368.64	4253177.62	48.87	26.30		0.00	0.017				0.266	
Ground Truth													OE Scrap, 6 in chunk (2 lb), 6 in deep, under Flag
MP Mag ACO	15	316380.57	4253186.01	60.81	34.69	0.31		0.122	0.9871	5	349	0.574	
MP EM ACO	53	316380.99	4253186.27	61.22	34.95		0.00	0.036				0.797	

Table 7. Survey Analysis of the Man-Portable Targets in the Woods

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													OE frag, 15 in flat, 4 in deep, 6 in SW of Flag
MP Mag ACO	16	316387.32	4253189.30	67.56	37.98	0.27		0.130	1.1858	24	27	0.924	
MP EM ACO	52	316387.44	4253189.37	67.68	38.05		0.16	0.094				0.913	
Ground Truth													OE Frag, 4 in flat, 4 in deep, 4 in SW of Flag
MP Mag ACO	17	316394.48	4253187.97	74.72	36.65	0.24		0.082	0.2997	8	185	0.987	
MP EM ACO													
Ground Truth													Piece of Cable, Near Surface, 3 ft SW of Flag
MP Mag ACO	18	316404.14	4253188.09	84.37	36.77	0.29		0.317	17.3538	63	103	0.785	
MP EM ACO	51	316404.17	4253188.00	84.41	36.68		0.18	0.078				0.668	
Ground Truth													OE Frag, (4 oz), 10 in deep, Flag 8 in S, 10 in W
MP Mag ACO	19	316418.88	4253184.57	99.11	33.25	0.55		0.072	0.2046	46	345	0.763	
MP EM ACO	65	316419.55	4253184.27	99.78	32.95		0.00	0.009				0.028	
Ground Truth													OE Frag, 1 in X2 in X1/8 in, 4 in deep, Flag 4 in S, 10 in W
MP Mag ACO	20	316424.79	4253192.17	105.02	40.85	0.24		0.100	0.5379	-31	147	0.899	
MP EM ACO	63	316425.10	4253192.08	105.33	40.76		0.06	0.037				0.448	
Ground Truth													OE Scrap, 3 in flat, 6 in deep, flag 6 in W
MP Mag ACO	21	316432.08	4253200.14	112.32	48.82	0.15		0.066	0.1578	1	225	0.865	
MP EM ACO													
Ground Truth													OE Frag, 3 in flat, 3 in deep, Flag 10 in NW
MP Mag ACO	22	316434.18	4253205.84	114.42	54.52	0.17		0.076	0.2413	15	269	0.777	
MP EM ACO	49	316432.46	4253206.27	112.70	54.95		0.49	0.072				0.453	
Ground Truth													OE Frag, 3.3 in flat, 4 in deep, Flag 3in NW
MP Mag ACO	23	316438.89	4253205.66	119.13	54.34	0.20		0.084	0.3196	33	142	0.973	
MP EM ACO	47	316438.54	4253205.07	118.78	53.75		0.11	0.039				0.387	
Ground Truth													OE Frag, 25 in flat, 3 in deep, Flag 3 in NW
MP Mag ACO	24	316442.62	4253205.14	122.86	53.82	0.28		0.066	0.1531	6	307	0.634	
MP EM ACO													
Ground Truth													Coiled up cable, 4 in deep, Flag 3 in SE
MP Mag ACO	25	316448.74	4253203.20	128.98	51.88	0.19		0.079	0.2670	5	313	0.850	
MP EM ACO													

Table 7. Survey Analysis of the Man-Portable Targets in the Woods

Survey/Analysis	Survey Target ID	UTM X(m)	UTM Y (m)	Local X (m)	Local Y (m)	Mag Depth (m)	EM Depth (m)	Size (m)	Moment	Inclin. (deg)	Azim. (deg)	Fit Quality	UXO Supervisor, Field Comments
Ground Truth													OE Frag, 1 in X 3 in X 1/8 in, Flag 7 in SE
MP Mag ACO	26	316454.12	4253202.57	134.36	51.25	0.21		0.071	0.1945	42	322	0.701	
MP EM ACO													
Ground Truth													Frag, 1 oz, 6 in deep, Flag4 in E, 1 in N
MP Mag ACO	27	316456.17	4253204.19	136.41	52.87	0.23		0.068	0.1727	-2	32	0.842	
MP EM ACO													
Ground Truth													OE Frag, 8 in deep, flat, Flag 4in S, 2 in E
MP Mag ACO	28	316458.57	4253199.60	138.81	48.28	0.42		0.082	0.3042	-1	144	0.909	
MP EM ACO													
Ground Truth													OE Frag, 3.5 in X1 in X1/4 in, near surface, Flag 3 in N, 2 in W
MP Mag ACO	29	316450.96	4253186.14	131.19	34.82	0.18		0.075	0.2333	-23	109	0.844	
MP EM ACO													
Ground Truth													Ball of wire, 4 in deep, Flag 6 in N
MP Mag ACO	30	316467.71	4253181.35	147.94	30.03	0.25		0.080	0.2792	43	22	0.866	
MP EM ACO													
Ground Truth													OE Frag, 4.5 in flat, 4.5 in deep, Flag 4 in E, 6 in N
MP Mag ACO	31	316437.54	4253176.01	117.78	24.69	0.24		0.075	0.2261	12	108	0.869	
MP EM ACO	57	316436.22	4253175.75	116.46	24.43		0.00	0.029				0.229	
Ground Truth													OE Frag, Near Surface, Flag 2 in S, 4 in W
MP Mag ACO	32	316422.06	4253172.74	102.30	21.42	0.21		0.048	0.0596	89	218	0.662	
MP EM ACO													
Ground Truth													OE Frag, 2 in deep, flat, Flag 2 in E, 7 in S
MP Mag ACO	33	316427.18	4253180.85	107.42	29.53	0.14		0.070	0.1841	-20	311	0.763	
MP EM ACO													
Ground Truth													Can, 3 in diam, 4 in long, 5 in deep, Flag 8 in N, 8 in W
MP Mag ACO	34	316435.00	4253181.35	115.23	30.03	0.21		0.049	0.0633	75	11	0.930	
MP EM ACO	59	316435.18	4253180.19	115.41	28.87		0.00	0.004				0.008	
Ground Truth													Coil of 1/4 in Cable,10 in deep, Flag 12 I S, 17 in W
MP Mag ACO	35	316418.22	4253179.12	98.46	27.80	0.41		0.125	1.0500	-6	105	0.928	
MP EM ACO													
Ground Truth													OE Frag, 4 in diam, 8 in deep, Flag 2 in S
MP Mag ACO	36	316390.15	4253189.85	70.38	38.53	0.23		0.073	0.2085	10	249	0.928	
MP EM ACO	64	316390.45	4253190.34	70.69	39.02		0.00	0.013				0.109	

Table 8. Results of Target Recovery in the Man-Portable Survey Area.

Item	Seed Targets	71-mm Mortar	81-mm Mortar	4.2-in Mortar	25-lb Frag Bomb	5-in Rocke t	OE Scrap	Non-OE Scrap
Number Recovered	18	1	14	1	1	1	43	11

The recovered OE scrap items included shrapnel, tail fin assemblies, spent fuzes, etc. Non-ordnance related materials included pieces of iron or steel such as angle iron, bolts, and hardware or coils of wire or cable. Not all of the recovered ordnance items were completely intact. Some were split, broken, or significantly bent. Several ordnance items were challenged with 1-in shape charges. None of the recovered items were fuzed nor contained explosive fills. All recovered materials (except the seed ordnance) were certified by the UXO supervisor as free of explosives contamination and disposed of by a commercial waste hauler.

5.2 Data Assessment and Technology Comparisons

Performance evaluation criteria include system detection sensitivity, accuracy of location and depth predictions, navigation system performance, and operational and ergonomic efficiency of the man-portable units.

5.2.1 Detection Sensitivity The ability to detect targets primarily depends upon the sensitivity of the sensors, the completeness of the survey coverage, and the signal to noise ratio in the survey data. The MMS system uses the same sensors as the *MTADS* vehicular system. The sensor horizontal separation and height above the ground are identical to the vehicular system and data sampling rates are such that the sampling density of the two systems are approximately equivalent. The signal to noise ratios in data taken by the two systems are also similar. Carefully laid out surveys conducted with the MMS provide similar detection and performance capabilities to the vehicular system. Data from the two systems is effectively equivalent, interchangeable, and indistinguishable.

The EMMS, as it was configured for the L-Range demonstration, could be deployed with either one meter square coils or with 0.5 X 1.0 meter coils. Only the latter system was used in this demonstration. These coil systems, specially manufactured for this application, supposedly had the same design as the individual units in the vehicular system. On a simple scaling basis, based upon the areas of the send and receive coils and a 50% overlap of transmitters in the vehicular system, one would expect that the individual half meter instrument might record 6 times lower signal strengths than the vehicular system for the same test object. While this would lower the sensitivity of the EMMS relative to the array, we did not expect that this would significantly limit our ability to detect (particularly shallow) targets because the array system is extremely sensitive for small shallow targets. In reality, the new coil systems were not completely equivalent to the units in the *MTADS* array. Measurements with electronic test equipment showed somewhat different system

set up parameters, and measurements on a test stand using standard objects confirmed the lower sensitivity. In addition, as deployed at the L-Range the EMMS using the wheel mounting system supplied with the instrument, placed the lower coil 0.4 meters above the ground. The vehicular *MTADS*, depending upon the suspension system being used on the tow vehicle, typically deploys the coils about 0.25 meters above the ground. Figure 9 shows a comparison of a small part of the L-Range survey area taken from the vehicular and man-portable surveys. Note the difference in display scales. The EMMS, as it was used in this demonstration, is 10-15 times less sensitive than the vehicular *MTADS*. The absolute differences are also a function of the size and depth of the test objects. The EMMS, as it was configured for this demonstration, provides data sample densities equivalent to, or slightly higher, than the vehicular system. The deployment of the GPS antenna high above the coils on the EMMS (Figure 1) introduces an additional noise source in the data. When the system traverses over rough areas side-to-side rocking motions can easily displace the antenna by half a meter horizontally from the center of the coils. Because the system is behind the operator, this motion is often not noticed or controlled. The acoustic navigation system transmitter does not significantly interfere with the EM sensor. The transmitter is typically deployed at the center of the upper EMMS coil.

The ability to detect a target also obviously depends upon the ability to deploy the sensor. In this demonstration much of the survey area was in the woods and much of the area was left relatively uncleared to test the ability of the man–portable systems to survey under realistic conditions. The EMMS coils were deployed in the narrow (0.5 meter wide) orientation and 0.25 meter survey lanes were used to maximize coverage. The area coverage in the open areas was relatively good, as shown in Figure 7. Our coverage in the wooded areas was, in retrospect, unsatisfactory. Relatively large areas were left unsurveyed. Some of the area was effectively inaccessible because of system design limitations. The difficulty of using the EMMS in tight areas, combined with excessive backpack loads, difficulty in following lane layouts, poor site survey management, and operator frustration all contributed to performance.

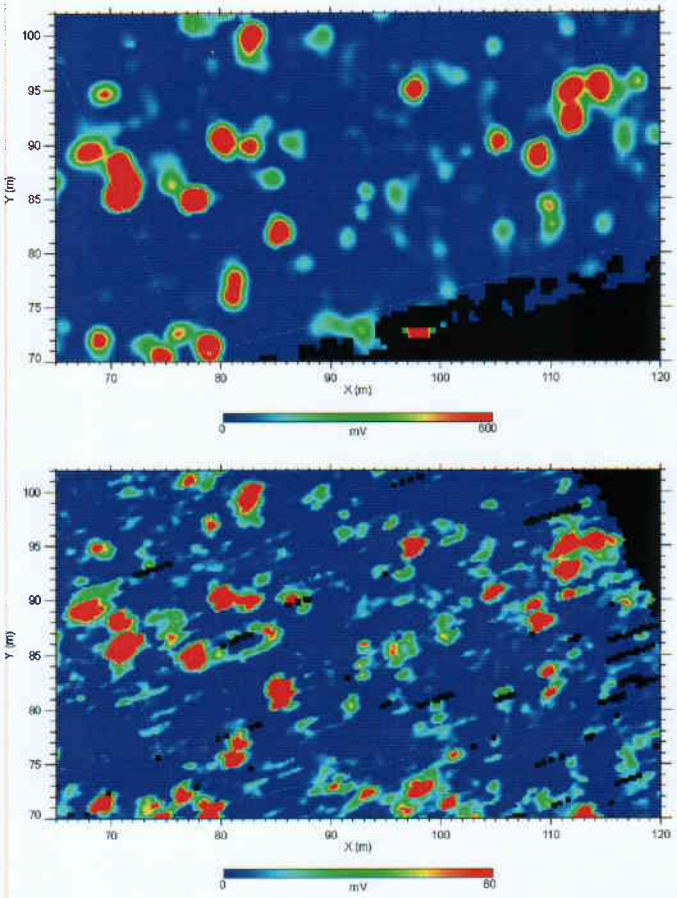

Figure 9. EM surveys from the L-Range. The upper image is from a vehicular *MTADS* survey. In the lower image the EMMS 0.5 X 1.0 m coils were used in a survey guided by the acoustic navigation system.

The survey performance in the

woods could have been improved by either conducting a second survey in an orthogonal direction to fill in some of the missed areas or by using the bush hog to clear remaining brush and undergrowth before a resurvey. In reality, however, the primary lesson learned from the EMMS deployment at the L-Range was that more development was required.

5.2.2 Missed Targets In this demonstration system performance was measured primarily against the seeded targets and secondarily, we considered the performance of the man-portable systems relative to the vehicular *MTADS*, the performance of the man-portable systems using GPS versus acoustic navigation, and finally the performance of the MMS compared to the EMMS. As shown in Tables 5, 6 and 7, the MMS detected all the targets that were characterized using the vehicular magnetometer array. With one exception, all the seed targets were detected and analyzed in each of the surveys that covered their positions. Seed target, T-14, was not detected by the EMMS because it fell in a missed survey area.

In the EMMS survey using GPS navigation, 14 targets were missed that were characterized in vehicular EM survey, and in all the magnetometer surveys. Coverage by the EMMS in the open range area was good. In all cases the targets were missed because, either there was no measurable signal in the EM data, or the signal-to-noise ratio placed the targets below the limits required for analysis. These results are summarized in Table 6. In general, in EM data a target described by a dozen data points with a signal-to-noise of >3 are sufficient to designate a target and converge to a fit using the analysis algorithm (although the fit quality may be minimal for this limited amount of data). The navigation error created by the rocking GPS antenna created an additional noise source which tended to smear out a target signal and make it very ragged (see Fig. 9). In some cases this created a situation in which the fit would not converge, in other cases it was difficult to recognize a target signal in a relatively noisy background.

Performance evaluation on the entire range area can be made by comparison of the MMS and EMMS surveys using the acoustic navigation system. The MMS survey contains 21 targets that were undetected in the EMMS survey. Of the 21 missed targets, 9 targets (in the woods) were in areas missed by the EMMS survey. In the remainder of the cases, the EM signal was undetectable or too weak for analysis.

5.2.3 Target Location Figure 10 shows a plot of the performance of the various systems in locating the positions of the seed targets. The ground truth positions are those measured by the surveyor when the targets were buried. The results are summarized in Table 9.

The location and depth prediction capabilities of the vehicular *MTADS* systems were equivalent to the system performance in many prior demonstrations. Targets are typically located to within 10-15 cm with the magnetometer array and 20-25 cm with the EM array. Depth predictions of the *MTADS* DAS based upon magnetometer data are typically within the volume of the UXO item. Depth predictions using the point dipole algorithm with EM data are less reliable. The vehicular magnetometer survey and the MMS/GPS survey results demonstrate that the MMS can provide equivalent field performance to the vehicular system.

Table 9. Errors in location and depth predictions for the seed targets at the L-Range

Survey	Vehicular Mag/GPS	Vehicular EM/GPS	MMS/ GPS	MMS/ Acoustic	EMMS/ GPS	EMMS/ Acoustic
Horizontal Error (cm)	11	21	11	43	26	60
Depth Error (cm)	5	29	5	11	(*)	(*)

(*) At this time the fitting algorithms in the DAS were not calibrated with the new coil signals to provide meaningful depth predictions.

5.2.4 The Acoustic Navigation System Use of the acoustic navigation system degrades the location accuracy over the GPS system. With careful use, however, position uncertainties of 0.25 meter with the acoustic navigation system, can be used to hold target location capabilities to 0.5 meter. In conducting acoustic navigation surveys in open areas, site dimensions should not exceed 200 feet in any direction. Antenna locations should surround the perimeter of the site and it is helpful to have an antenna centrally located within the site. System performance degrades when there is a high background noise interference. Even wind blowing through knee-high grass raises the operational threshold of the antennas (to exclude noise) to a level that noticeably degrades system performance.

A single antenna setup was used to survey the wooded part of the L-Range. This setup worked satisfactorily even though many of the antennas were not directly (line of sight) visible to each other because of elevation changes or because trees and brush seriously obstructed visibility. A careful initial setup is required. Three of the antenna positions should be at known coordinates and it is advised that system performance be evaluated against a known position within the survey before undertaking a survey. Even though this system is difficult to use, it is the best available (non-GPS) automated navigation/location system that can be used to conduct digitally mapped UXO surveys.

5.2.5 System Ergonomics
Mechanically, the MMS performed satisfactorily in the L-Range demonstration and the system performance as a UXO survey tool met all system design specifications. However, as outlined in Sections 2.3.1, we felt that the system was not appropriate for transition to commercial applications where it would be used in much more demanding conditions by much less skilled operators. We undertook system modifications, as described below, to ergonomically improve the system so that it could be successful in commercial applications.

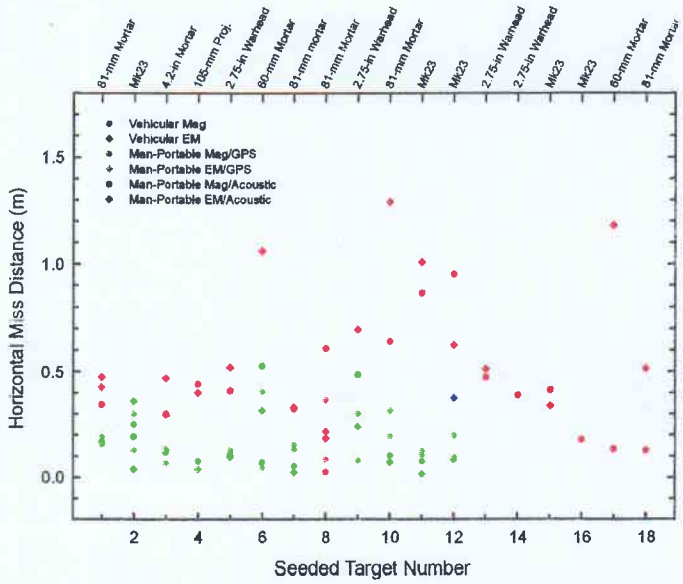

Figure10. Comparison of the horizontal location accuracies for the seed targets at the L-Range.

The EMMS system performance was disappointing on several levels. Cost constraints in system development and integration led to use of existing equipment that was too heavy and bulky for backpack applications. The system design, based upon a narrow coil on a trailing cart supported by high wheels, had a poor usability. The electronic performance of the newly-purchased coil systems proved to be too insensitive for dependable UXO surveys for either shallow or deep targets. The poor ergonomic design and limiting electronic design frustrated the performance in the demonstration. A complete redesign of the EMMS was undertaken in preparation for the final demonstration. See Section 6 of this document.

6.0 Final System Prototype Modifications

6.1 Component Changes in the Final Prototypes

Following the L-Range demonstration we felt that an additional round of system development and a new system demonstration was required to produce *MTADS* man-portable adjuncts that would be directly commercializable. ESTCP supported this development.[14] In addition, a modest amount of funds remaining on the NRL/Blackhawk Geometrics CRADA were devoted to this project.[21] As described in later sections, the final prototypes were demonstrated at field surveys at the Jefferson Proving Ground in the summer of 2000.[19]

6.2 Subsystem Component Upgrades

Based upon the original Man-Portable Program Development Plan we reconsidered each of the subsystem components from a requirements and performance point of view. We considered the impact of these decisions on the MMS and EMMS overall system requirements and performance expectations. Only one significant change was made in the initial system performance specifications. Given the difference in performance of the vehicular EM array, and what would become the final man-portable EM array, it was unrealistic to attempt to develop the DAS so that man-portable and vehicular EM survey data could be used interchangeably. Ultimately the DAS was modified to separately accept and fit either vehicular or EMMS data, but no attempt was made to create a conversion that would make the two data sets equivalent.

6.2.1 Cabling The cables and connectors used to interconnect the various system components (batteries, sensors, navigation components and data logger) as used at the L-Range demonstration were too large in number and not rugged enough for sustained field work. We redesigned the cabling for both prototypes. The number of cables was reduced. The new cables have improved strain-relieved connectors, and they are designed for connection to interface plates in the new backpacks. Spares were manufactured or purchased for each cable.

6.2.2 Batteries Each individual component of the man-portable prototypes was delivered by its manufacturer with an individual battery pack. The capacity of these battery packs ranged from several days for the acoustic location system to1.25 hours for the EM-61. In operation, this meant that we had to stop to change the EM battery every hour while carrying other heavy long-lived batteries. New battery requirements were established and battery performance tests were

undertaken to design new battery packs minimizing carry weight while allowing one hour performance with a 25% excess capacity. Some of the battery performance tests are included in the Appendix. These measurements were done to assure that the chosen battery systems could meet the requirements under all expected field conditions. Delivery of the new EM coils (see below) required carrying a new heavy lead acid battery to power the coils. This new battery was placed on the new system cart as discussed below. Battery chargers and batteries were purchased that would allow day long continuous use. Packing and shipping cases for these items were purchased or constructed.

6.2.3 Data logger The modifications we originally made to the standard Geometrics 858 data recorder (Figure 3) greatly increased its flexibility and usability with the MMS and the EMMS. One remaining shortcoming required modification. The operator did not have real-time display access to the quality of the GPS fix. For the Demonstrations at the L Range, fix quality requirements were accommodated by planning to work in times of good satellite visibility. In a real-world environment this would be unacceptable. We arranged with the manufacturer to carry out additional modifications to the data logger to display the GPS fix quality and to sound an alarm when the quality drops below Fix Quality 3. The Geometrics 858 data logger, as modified for this program, is now commercially available from Geometrics for purchase, or from their equipment rental pool.

6.2.4 The MMS Sensor Cart For the L Range Demonstration we designed a magnetometer cart with mounts for the antenna/transponder location with an emphasis on ease of use and minimizing weight. The cart performed acceptably for the tests. The tests were not in difficult terrain, however. Subsequent analysis showed that a major increase in strength and reliability could be obtained with a small weight penalty.

We redesigned, engineered, and manufactured a new magnetometer cart with improved ruggedness and a better ergonomic design. The engineering drawings for the new magnetometer cart are included as an appendix on the CD-ROM included with this report. The new cart, shown in Figure 11 set up for a GPS survey, is constructed of a combination of fiberglass and plastic components. The wheels have been placed side by side between the sensors. This design works better in tight spaces and on more rugged and uneven terrain. The hood, as shown in Figure 12, covers and protects the sensors and the antenna and allows the system to slide through grass and low brush without snagging the cart or sensors. The height of the handles and the weight that the operator has to carry in his hands represents a considerable ergonomic improvement from the earlier design. The complete system can be operated by a single operator for an extended time without tiring. With the hood the MMS weighs 52 lbs, without the hood the weight is 38 lbs. The total backpack weight is 18 lbs (GPS antenna).

6.2.5 The EMMS Cart In the case of the EM-61, deploying the prototype with the wheels provided by the manufacturer positions the transmit coil 40-cm above the ground. Since the measured EM signal falls off as $1/r^6$, a large increase in signal (and thus sensitivity for relatively shallow objects) could be obtained by lowering the sensor. Following delivery and acceptance of the new EM sensor (see below) we designed and build a new EM cart to support the system. It is more rugged, more pitch and roll stable, provides a better weight balance in front and behind the wheels to minimize carry weight for the operator, and incorporates a new design that put the sensors

Figure 11. The MMS is shown deployed with the protective hood and the GPS navigation hardware.

Figure 12. The MMS is shown as deployed on Area 3 at the Jefferson Proving Ground.

in front of the operator.

The engineering drawings for the new EM carts are included as an appendix on the CD-ROM included with this report. Sensor trays were designed so that the sensor can be mounted with the long dimension across the track, Figure 13, or pointing down the track, Figure 14. The new sensor coils require the use of a heavy lead-acid battery for power. The battery is mounted in different positions, depending upon the orientation of the coils, to balance the weight load over the wheels. The weight that the operator has to lift is not large, however, the weight of the total system including battery, cart, and coils, and antenna is 110 pounds. Pushing this sized load proved to be difficult when terrain conditions were very rugged, or when the survey area was deep mud. These operational issues are discussed in more detail in the presentation of results for the JPG demonstration. The system battery was oriented and positioned to minimize signal from the plates at the receive coils. The newly designed backpack and system components allow the operator to carry all components in a 31-lb backpack. The system is designed to collect data for one hour

Figure 13. The EMMS is shown with the digital inclinometer and the GPS navigation system as deployed at the Jefferson Proving Ground

Figure 14. The EMMS is shown with the coil mounted with the 0.5-m dimension pointing down the survey track.

before battery change out. The MMS and EMMS, when deployed with the acoustic navigation system, has the ceramic transmitter deployed immediately above the sensors. The transmitter does not interfere with either the magnetometers or the EM sensors. The transmitter is shown deployed on the EMMS in Figure 15.

Figure 15. The EMMS is shown deployed with the Chemrad acoustic navigation transponder.

6.2.6 The New EM Coil After reviewing the performance characteristics of the EMMS in the L-Range Demonstration with the manufacturer, a new 0.5 X 1.0 m coil system was developed by Geonics for our use. The coil underwent extensive testing at our Blossom Point facility which resulted in further fine tuning of the coil performance specifications. The present EMMS coil is much more sensitive than any prior EM-61 type system that we have tested. This improved sensitivity was accomplished by making many changes in the system design. Both the transmit power and the signal detection sensitivities were improved by making numerous changes in the coil design, the power delivery system, and the detection electronics. Some of these design changes are proprietary to the manufacturer. However, the coil as currently deployed on the EMMS, can now be purchased as a standard product from the manufacturer. The increased transmission power has required a substantial increase in battery capacity to power the system. We tested several lead-acid deep discharge batteries before specifying the present system. Since the batteries must be recharged after one hour of use, the correct choice was considered important. Based upon the battery performance tests we chose the Powersonic Model 12330 (33 amp-hours). A battery charging system was purchased that will allow us to simultaneously charge 5 batteries which are needed to continuously operate for a full day.

6.2.7 The DAS The *MTADS* data analysis system underwent an upgrade to accommodate the new developments in this program and other ongoing ESTCP UXO programs. The new EM coil system (Figures 13-15) was extensively characterized on a test stand to determine its response to standard metal test objects. In addition, the coil was used to resurvey the Blossom Point Magnetic Test Range for comparison with earlier systems. The absolute sensitivity of the 0.5 X 1.0 m coil system is compared to the vehicular array and to the coil system used for the L-Range demonstration in Figure 16. The absolute value of the relative sensitivities is mildly dependent on the depth, size, and composition of the test object, but in all cases, the new coil has an equivalent or greater detection sensitivity than a single unit of the vehicular array. These measurements and results are described in an internal report titled "New Coil calibration Report" which is included in Appendix D. The current DAS has switches to allow target analysis of survey data with algorithms tailored for the new coil. As part of the shakedown process for the new MMS and EMMS instruments new data sets were taken in our test pit for a wide range of inert ordnance items. These are incorporated into our ordnance library.

7.0 JPG-V Demonstration Approach

The FY-2000 demonstrations at the Jefferson Proving Ground were jointly sponsored by ESTCP, AEC, US Army Engineer R&D Center , and NEODTD.[19] The survey test areas consisted of three 1-hectare prepared sites. The demonstration approach was built around a scenario intended to evaluate technologies that might address the particular demands of the Kaho'olawe Island cleanup. Both inert UXO, OE scrap, and magnetic soils/rocks were incorporated into the test. Two of the three sites took advantage of naturally occurring magnetic soil deposits. These were augmented by soil/rock samples from Hawaii. The third site was geologically relatively benign. Three demonstrators were invited to participate using active electromagnetic sensors. These included the most recent *MTADS* variant of the Geonics EM-61, a variant of the Geophex GEM Sensor, and the Geonics EM-63 sensor. Each demonstrator was required to conduct digitally-mapped geo-referenced surveys and to conduct target analyses on site as though concurrent remediation would take place.

NRL, using magnetometer arrays (both vehicular and man-portable), independently conducted magnetometer surveys of each of the 1-hectare sites. These data were preprocessed to create geo-referenced mapped data files that were provided to each of the other demonstrators and are included in Appendix F of this document. All demonstrators were invited to incorporate the magnetometer data into a sensor fusion analysis and to provide these analyses to the US Army Engineer R&D Center within 30 days of their site visits.

All demonstrators worked to a common Demonstration Test Plan issued by NEODTD.[24] This Plan is included as Appendix F to this document. Ten types of inert ordnance were included, varying in size from 20-mm aircraft-fired projectiles to 155-mm howitzer projectiles. Examples of these items were provided to each demonstrator for study and calibration prior to their site surveys. Demonstrators were told that emplaced inert ordnance was degaussed. The non-UXO items were not described (or provided) other than to state that they were realistic OE scrap.

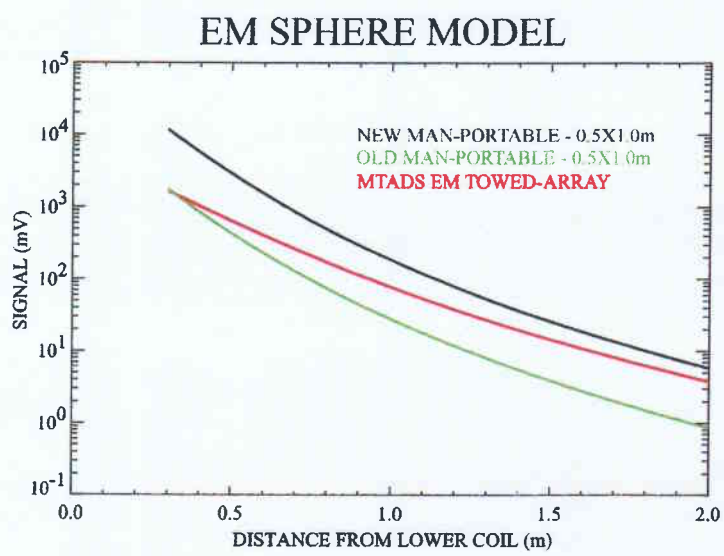

Figure 16. Relative response of various EMMS coil systems to a 4-in test sphere. The responses are for the lower coil of each system. The Towed-Array response is for a single coil of the three coil array.

7.1 JPG-V Performance Objectives

It was understood that the onsite EM surveys and analysis products would be evaluated on the basis of cost/production

rates, UXO detection rates, target location accuracy, UXO identification ability, and a probabilistic categorization of detected targets as UXO or not-UXO. Additionally, each demonstrator was asked to make recommendations in the target lists as to whether an item should be dug, or could be confidently left in the ground. Two independent analyses were to be submitted based upon the assumption that 20-mm projectiles either were, or were not, present.

Demonstrators were invited to provide additional analyses from their joint post processing of magnetometer and EM data. The evaluation criteria were assumed to be similar to those applied to the on-site analyses.

7.1.1 NRL Man-Portable System Objectives All sites were surveyed with the man-portable *MTADS* EM adjunct (the EMMS). All sites were surveyed with the *MTADS* vehicular magnetometer array. Site 3 only, was surveyed using the man-portable *MTADS* adjunct (the MMS). Our demonstration and evaluation of these instruments was the primary objective of this report. Additionally, we wished to compare their performance with the vehicular *MTADS* and with the other (more complex) EM sensor technologies.

7.1.2 NRL Data Analysis/Classification Objectives All EM data analyzed on site employed the *MTADS* DAS upgraded to carry out 3-β UXO classification target analyses based upon developments in ESTCP Program 199812.[17] Additional test pit measurements were made upon some of the inert UXO test items provided to each of the demonstrators when the mod or variant of the ordnance was different from those in our signature library. The objectives of the on-site analyses were to use this classifier and realistic size thresholds in the data analysis to discriminate between UXO and OE scrap. Therefore, this report also describes a blind test of the performance of the 3-β classifier.

7.2 JPG-VSampling and Analysis Procedures

7.2.1 3-β Classification of EM Data Many of the UXO items used at the JPG test site are very similar in size. Neither the magnetometer nor the EM analysis/classification routines can distinguish between them. These fitting uncertainties are further complicated by the noise sources introduced into the data by conditions of the survey field and the process of taking the data. One of the reporting requirements was to predict ordnance type. In general, our predictions of ordnance type were grouped into categories of similar sized items, i.e. 57/60-mm, 76/81-mm, 105mm/4.2-in, 152/155-mm, etc. In some situations, predicted sizes fell between more disparate items such as 60/81mm mortar, etc. Our type predictions attempted to reflect these uncertainties. It has been our experience that it does not matter at all to the UXO remediator whether we can distinguish among similar ordnance sizes. In general, size predictions resulting from combined EM and magnetometer analyses are more precise and reliable than those resulting from EM data alone. Data such as that shown in Figure 17 was used in making EM classifications. For instance, the dashed line was a trial value to use for minimum size threshold for UXO declarations assuming that 20-mm ordnance was not present. Based upon noise levels in the field data and complexity of some of the anomaly signatures, ultimately a 57-mm lower size threshold of 37 mm was chosen. Targets fitting to sizes smaller than 37 mm were classified as confidence level 5 or 6 based upon their beta coherence

values and other visual information about the target. Similar plots for other UXO were used as training data for classification decisions.

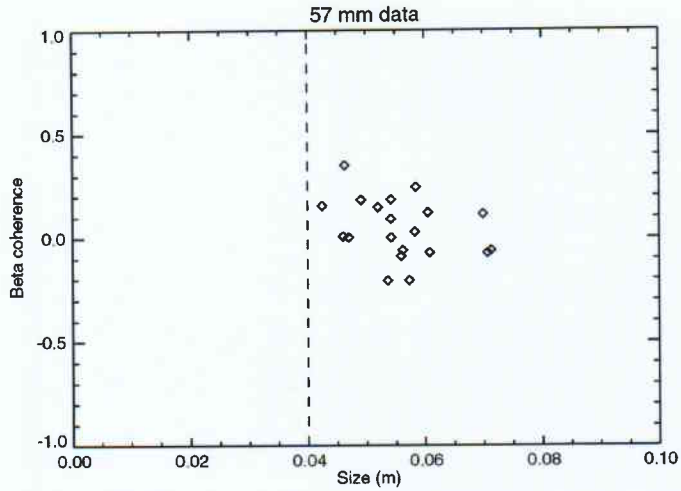

Figure 17. Plot of a parameter based upon the beta fitting values vs predicted size for 20 measurements of a 57-mm UXO target in a field survey.

An additional reporting requirement[24] asked that we rank each target (among all those reported) as to its relative probability of being UXO or "not-UXO." Neither our EM nor the magnetometer analysis tools lends itself to a mathematical probabilistic classification. In our EM data analysis the results of the 3-β classifier fit was used to predict UXO or "not-UXO," and to make decisions about which one of the 6 "confidence categories" to assign to the analysis. Our probabilistic ranking was reduced to binning all targets into these 6 probability categories. Categories 1-3 are classified as ordnance, category 1 includes items with the highest confidence ordnance assignment. Category 3 has the lowest confidence UXO assignment, but is more likely ordnance than not. Categories 4-6 are the mirror image scrap categories with 6 designated as most confident assignment as scrap. Assignments were made generally based upon the 3-β assignments.

An exception to this strictly 3-β based assigned scoring was the assignment to either confidence category 5 or 6. We recommended digging all targets with confidence classifications of 1-5. In some cases a 3-β classification of 6 was raised to 5 because we felt it was too risky to leave a specific item undug. It was felt that the spatial resolution available from the 1-meter coils might lead to mis-classifying a target if, for instance, a nearby clutter item became part of the analysis object. In later analyses, in numerous instances, anomalies analyzed as single targets in the EM analysis broke up into multiple targets or clusters of items in the magnetometer survey.

*7.2.2 **Joint Magnetometer and EM Analysis*** In the joint analysis which included the magnetometry data, the *MTADS* baseline point dipole fitting algorithm was applied to each anomaly declared in the EM data set. Additional targets were fit and/or declared based upon anomalies that did not appear (or were rejected for analysis) in the EM data set. In assigning decisions in the joint analysis, the 3-β EM classification was accepted as a starting point. Modifications were made to the 3-β classification when it was clear that additional information was present in the magnetometry signature. In a few instances magnetometry targets were selected that were not visible in the EM data. These were mostly deep targets and some may be associated with geological formations. If a magnetic anomaly fit an ordnance profile in the magnetometry data, and if it was deep enough that it might be undetectable in the EM survey, it was chosen for digging. Some EM classifications were changed based upon the magnetometry analyses. These fell into two categories. Targets with strong remnant moments and/or inverted signatures were classified as OE

scrap and usually reduced to category 6 (Don't Dig). EM anomalies that appeared as multiple targets in the magnetometry analysis were reclassified based upon their magnetometry analysis. A few targets were reclassified in the joint analysis based upon their predicted size in the magnetometry analysis if it was felt that they clearly did not fit size thresholds required to be UXO.

7.3 JPG-V - Physical Setup and Operation

The JPG-V demonstration was conducted under the guidance of the JPG Work Plan and in accordance with the NRL Demonstration Work Plan. Each of these documents is included in Appendx F on CD-ROM attached to this report. NRL was allotted a time slot of 27 August-6 September to conduct the demonstration. On 27 August, the equipment was deployed to the site. All data analysis equipment was unloaded into the office trailer and set up for operation. Field radios and rechargeable batteries were setup in the office trailer and plugged in for recharging. The survey equipment was unloaded into the equipment storage area about 0.75 miles away and the EMMS was assembled.

Area 3 was staked, gridded and surveyed with the EMMS on 28 August. Area 1 was staked, gridded, and surveyed with the EMMS on 29 August. Area 2 was similarly completed on 30 August. The US Army Engineer R&D Center and NEODTC site managers maintained a detailed log of on site labor and production rates for the conduct of all surveys and analysis work. This log is included as an Appendix titled JPGsurveyLabor.xls. The setup and survey production rates are summarized in **Table 10**, below. The labor hours in the separate senior supervisor labor category in the JPGsurvey Labor.xls file were repartitioned into the appropriate working labor categories as shown below.

Table 10. Production rates associated with various JPG-V survey and analysis activities.

Survey	Area 3 (Man Hours)	Area 2 (Man Hours)	Area 1 (Man Hours)	Total (Man Hours)
Stake & Grid	9.5	9.2	10.3	29
EMMS Survey	18	21.5	19.3	59
EMMS Analysis (On Site)	20.5	18.8	23	62.5
Target Reports				23.5
MMS Survey	20			20
Vehicular Mag Survey	4.75	3.5	4.5	12.8
Clean Up/ Pack Out				15

Following completion of the EMMS surveys, two laborers from the local casual labor market were brought onboard to assist in conducting the man-portable MMS survey of Area 3, to flag for

the vehicular *MTADS* magnetometer survey of all three areas, and to participate in the cleanup and pack out. This allowed Dr. Bell and Dr. Nelson to participate in the final analysis and preparation of target reports for the EMMS surveys. On August 28-30, Dr. Nelson and Dr. Bell exclusively supported the EMMS field survey operations. Mr. Puc, for the most part, supported the data handling operations, taking the raw data from the field surveys, setting up the survey sites, and preprocessing and entering all the data into the survey files. He additionally preprocessed all MMS and vehicular EM survey data on site and participated in preparation of the EMMS target reports and dig images that were on-site deliverables for this project. Mr. Koppe supported all *MTADS* field operations. On 28 August and the morning of 29 August, Dr. McDonald supported the EMMS stake and gridding operations and the remainder of the time conducted the data analysis and target picking and preparation of EMMS data deliverables which were presented to the sponsor on 1 September.

7.3.1 EMMS 3-β Survey Products Area 3 was surveyed first. Prior to surveying, a 12 gauge wire was stretched 1.0 meter outside the east and west site boundaries to use for position and timing calibration. The first-order survey point adjacent to the site was used for the GPS base station for this survey (and for all other surveys). The site was gridded with wooden stakes at 1.5 meter intervals along the east and west site boundaries. Twine was pulled between stakes to define survey lanes. Lanes were surveyed at 0.5 meter separations. Figure 18 shows the EM anomaly image for Area 3. The analyzed target numbers are shown adjacent to the anomalies. The return from the calibration wire is shown outside the east and west site boundaries.

All analyses are provided as target tables on spreadsheets in Appendix G. The spreadsheets contain the target analyses that were provided to the sponsor on site for the EM surveys and by Email before the one month deadline for the joint EM and magnetometer analyses. There are four spreadsheets for each of the three sites. Data were analyzed twice, once assuming that 20-mm projectiles were present, and a second time assuming that 57-mm rifle grenades were the smallest UXO threat on site. Also included in the spreadsheets are ground truth summaries provided by Dr. Ernie Cespedes at the ESTCP Symposium and Workshop. The spreadsheets contain ground truth entries only for targets intentionally buried on the three areas. Subsequent to completion of all other activities, it was understood that the additional targets claimed by more than one of the demonstrators would be dug to determine the source of the observed anomalies. The EMMS survey results for Area 3 are provided below as summaries of the information in the worksheets in Tables 11 and 12.

7.3.2 The MMS-EMMS Joint Analysis Survey Products The magnetic anomaly map of the Area 3 vehicular survey is shown in Figure 19. Survey analysis spreadsheets are also provided in Appendix G for the results of the joint magnetometer and EM survey analyses. Again, ground truth, to the extent that it was available, is appended to the spreadsheets. The results for Area 3 are summarized below in Tables 13 and 14.

7.3.3. Comparison of the MMS and Vehicular Surveys Area 3 was surveyed with both the vehicular *MTADS* and the MMS system. Independent baseline target analyses were carried out on each data set. These analyses are compared in spreadsheets included in Appendix F of this report.

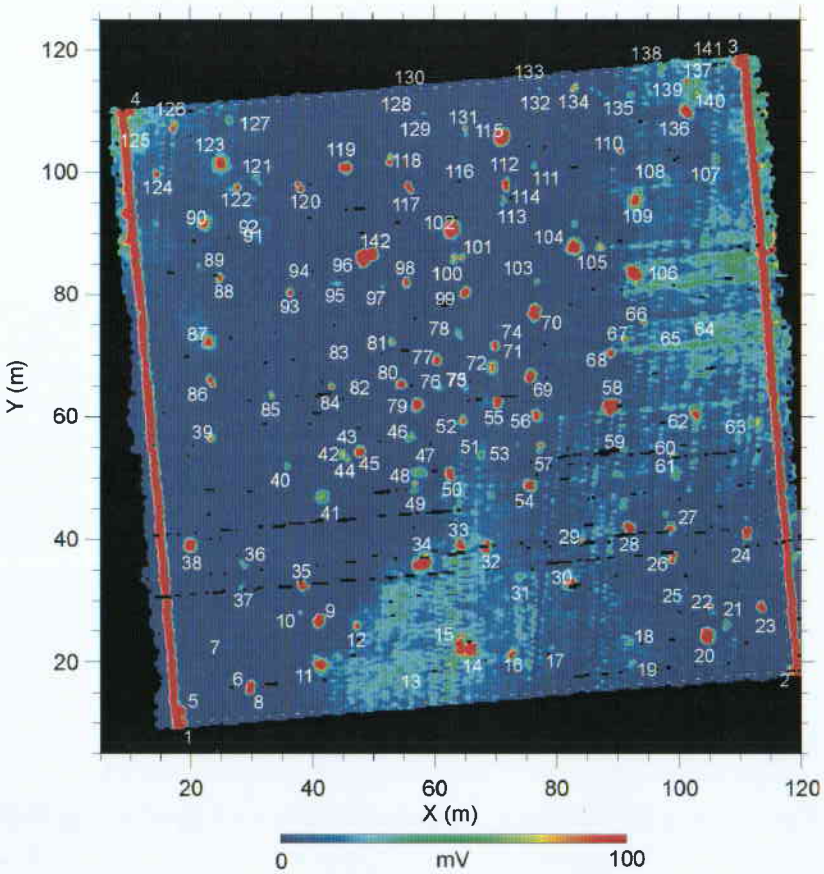

Figure 18. EM anomaly image of the Area 3 EMMS survey. Target numbers are shown beside the anomalies.

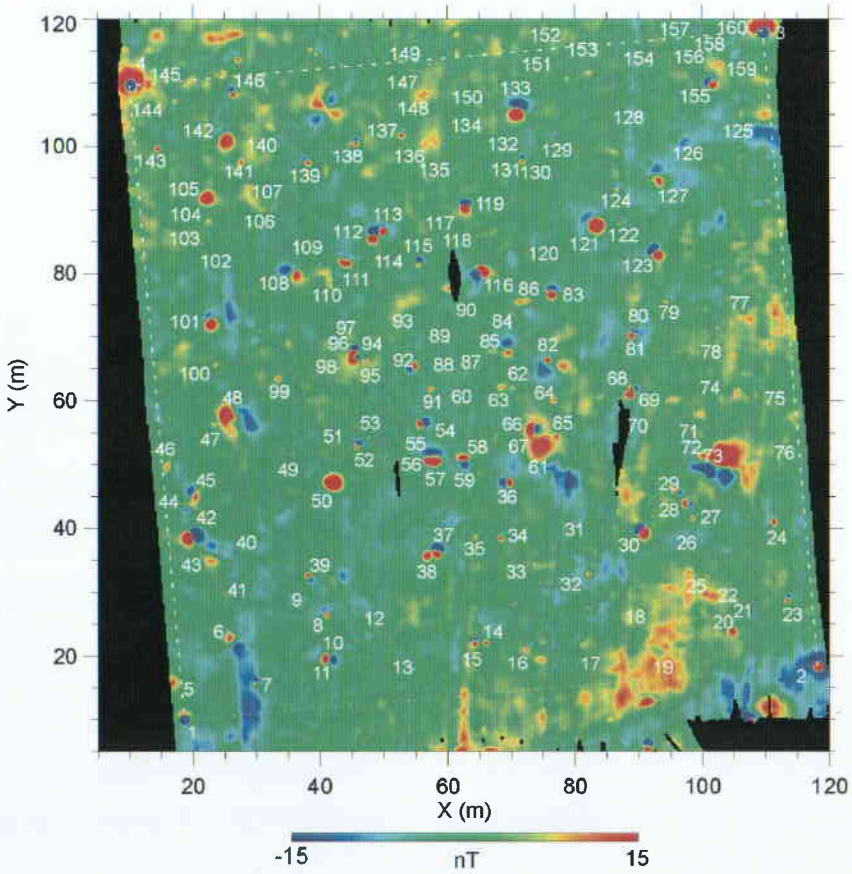

Figure 19. Magnetic anomaly image of Area 3 resulting from the vehicular *MTADS* survey. Target numbers from the joint analysis are shown.

Table 11. Area 3, EM Survey , 3–β Classification, Assuming 20-mm Projectiles are Present

Targets Declared	Targets Buried	UXO Detections	UXO Not Detected	Correct UXO Classifications	UXO Misclassified	UXO, Correct Type Assignment	Incorrect UXO Type Assignments	OE Scrap Correct Classification	OE Scrap Correctly Not Dug
134	55 20 UXO 35 OE	19	1 (81-mm)	13 of 19	4 (20-mm) 1 (60-mm) 1 (155-mm)	7 of 13	81mm as 105mm/4.2in 81mm as 2.75in 76mm as 57/60mm 105mm as 76/81mm 152mm as 105mm/4.2in 60mm as 76/81mm	11 of 29	4 of 29

Table 12. Area 3, EM Survey, 3-β Classification, Assuming 20-mm Projectiles are Not Present

Targets Declared	Targets Buried	UXO Detections	UXO Not Detected	Correct UXO Classifications	UXO Misclassified	UXO, Correct Type Assignment	Incorrect UXO Type Assignments	OE Scrap Correct Classification	OE Scrap Correctly Not Dug
134	55 16 UXO 39 OE	15	1 (60-mm)	12 of 15	1 (60-mm) 1 (81-mm) 1 (155-mm)	7 of 12	81mm as 105mm/4.2in 81mm as 2.75in 76mm as 57/60mm 105mm as 76/81mm 152mm as 105mm/4.2in	21 of 34	14 of 30

Table 13. Area 3, Joint Magnetometer and EM Survey, Joint Analysis Assuming 20-mm Projectiles are Present

Targets Declared	Targets Buried	UXO Detections	UXO Not Detected	Correct UXO Classifications	UXO Misclassified	UXO, Correct Type Assignment	Incorrect UXO Type Assignments	OE Scrap Correct Classification	OE Scrap Correctly Not Dug
154	55 20 UXO 35 OE	20	0	15 of 20	4 (20-mm) 1 (60-mm)	13 of 17	81mm as 57/60mm 76mm as 2.75in/81mm 105mm as 2.75in 60m as 76/81mm	20 of 33	10 of 33

Table 14. Area 3, Joint Magnetometer and EM Survey, Joint Analysis Assuming 20-mm Projectiles are Not Present

Targets Declared	Targets Buried	UXO Detections	UXO Not Detected	Correct UXO Classifications	UXO Misclassified	UXO, Correct Type Assignment	Incorrect UXO Type Assignments	OE Scrap Correct Classification	OE Scrap Correctly Not Dug
154	55 16 UXO 39 OE	16	0	14 of 16	1 (60-mm) 1 (81-mm)	12 of 16	81mm as 57/60mm 76mm as 2.75in/81mm 105mm as 2.75in 60m as 76/81mm	28 of 37	21 of 37

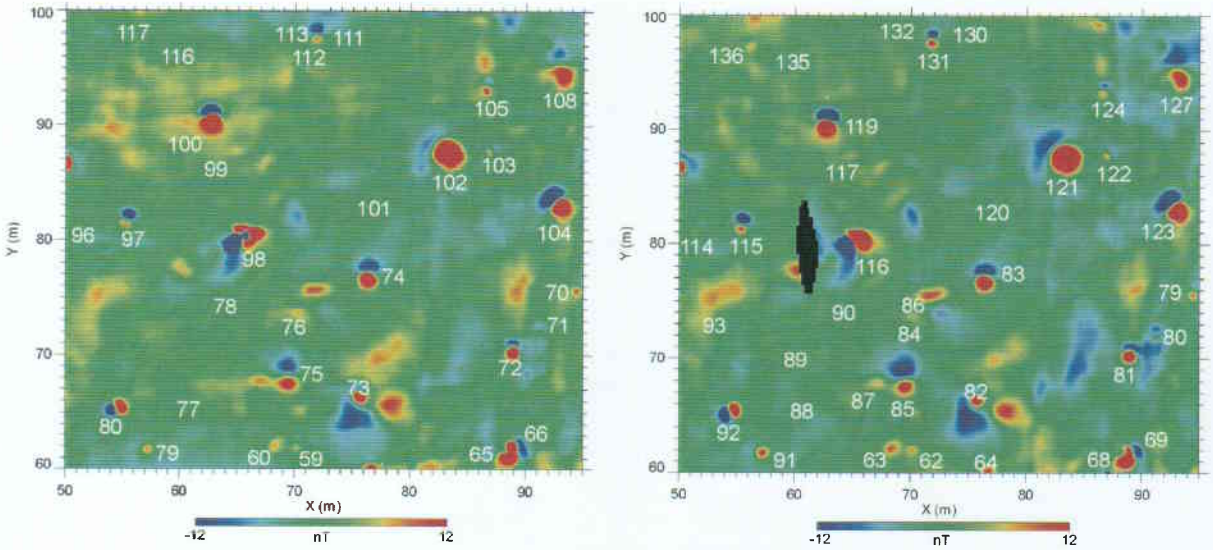

Figure 20. Magnetic anomaly image of part of Area 3. The MMS survey is shown on the left and the vehicular *MTADS* survey is shown on the right.

Figure 20 shows comparisons of images of mapped data files of a typical selected section of Area 3. Table 15 shows by way of comparison, that vehicular survey of Area 3 required 4.75 man-hours while staking, gridding and surveying of Area 3 with the MMS required 20 man hours of labor. The relative efficiencies of the vehicular survey was not fully demonstrated because well over half of the vehicular survey time was occupied in turns at the ends of the very short survey lanes on this one hectare site. The small missed area at about X=60, Y=80 meters in the vehicular survey involved maneuvering around a tree. This area was more effectively surveyed with the MMS. The noise levels in the MMS data are slightly higher than in the vehicular data, but not sufficiently so to significantly affect the quality of the analysis. Information from the two surveys is effectively interchangeable.

7.4 JPG-V Performance Assessment

7.4.1 Performance Data The surveys of Areas 1 and 2 reveal regions that are significantly more geologically active. The motion-induced noise in the EM image (Figure 18) results from surveying across shallow furrows dating from when the area was in cultivation prior to its use as a range. The EMMS and *MTADS* magnetometer survey images of Areas 1 and 2 are shown in Figures 21-24. The magnetic soil deposits distributed across much of Area 2, or in the ravines in Area 3, do not significantly interfere with the EM survey data. Their effect on the magnetometry data is much more pronounced. Target analysis of magnetometry data in these areas is much more tedious, requiring display of small areas with constant resetting of offsets and detrending during the fitting of individual targets. In general, with very careful analysis, 10 nT anomalies can be fit in regions with geological magnetic soil offsets of 200 nT. Small targets, such as 20-mm projectiles or 60-mm mortars, at depth, have a higher probability of going undetected in these areas, however.

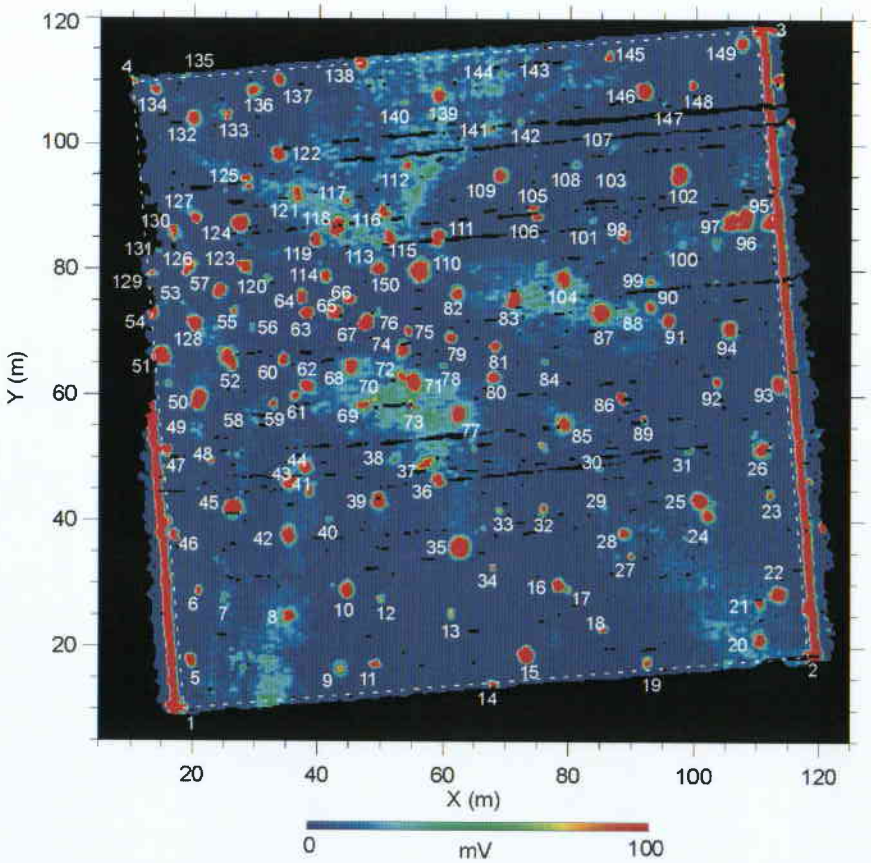

Figure 21. EMMS Survey of Area 1 at the Jefferson Proving Ground.

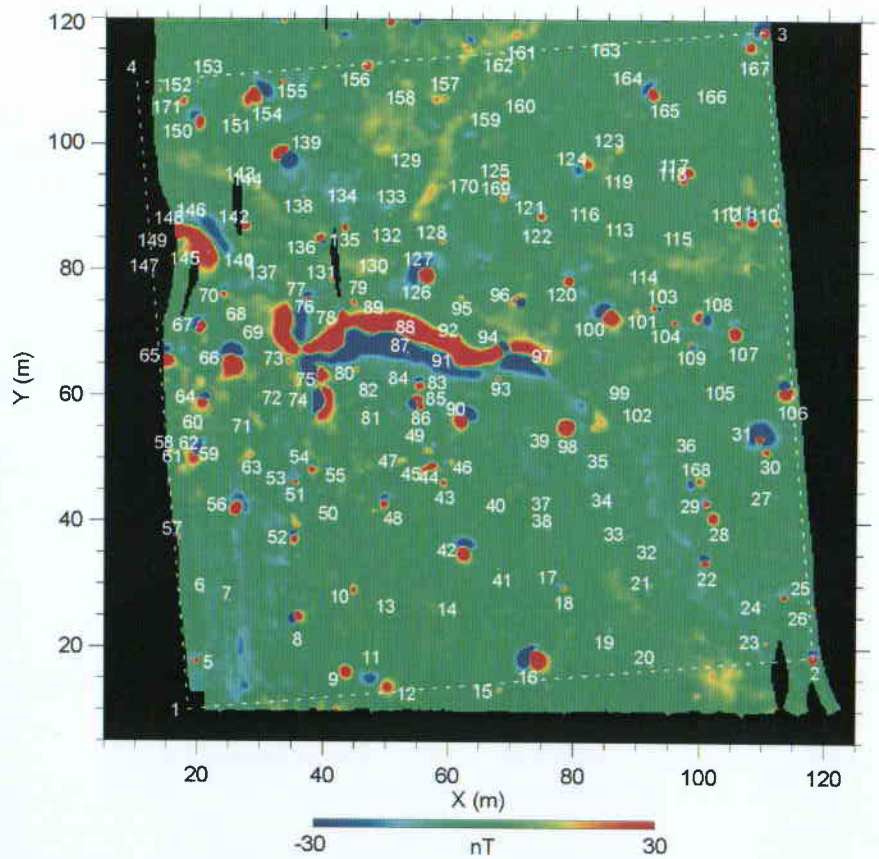

Figure 22. Vehicular *MTADS* magnetometer survey of Area 1 at the Jefferson Proving Ground.

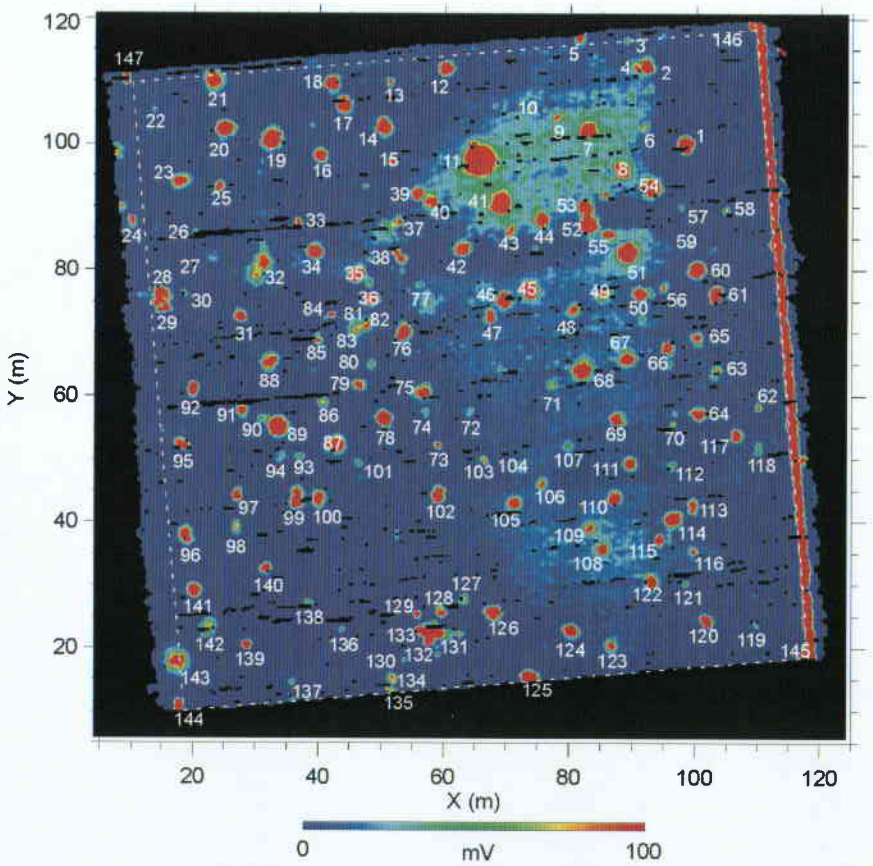

Figure 23. EM anomaly image from the EMMS survey of Area 2 at the Jefferson Proving Ground.

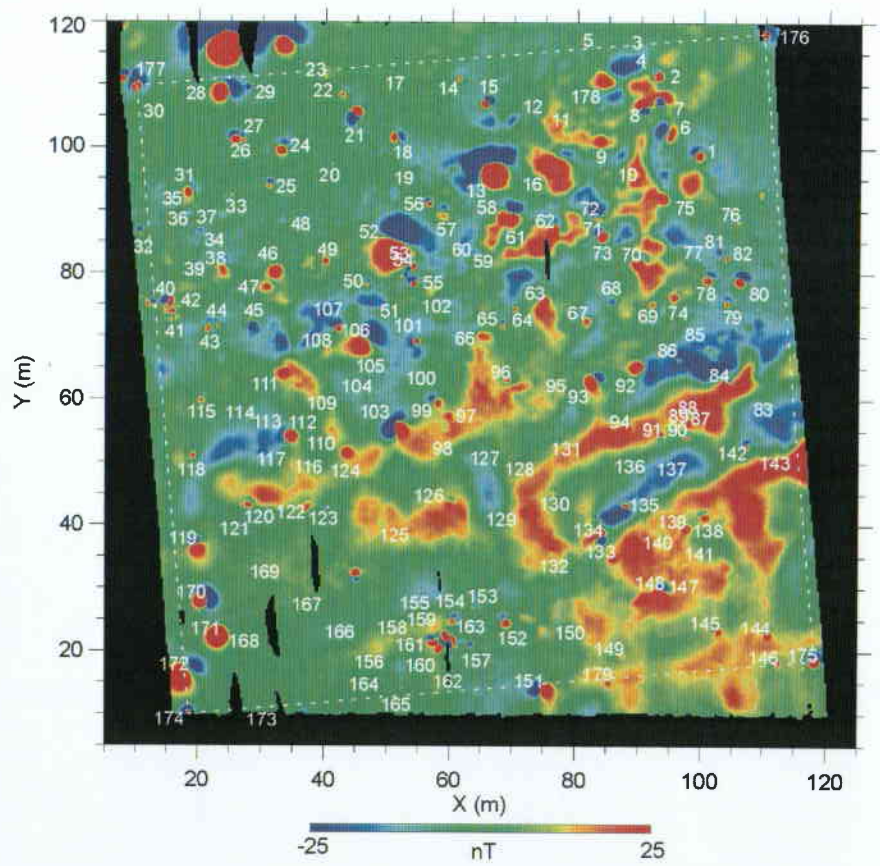

Figure 24. Magnetic anomaly image from a vehicular *MTADS* survey of Area 2 at the Jefferson Proving Ground.

7.4.2 Data Assessment and Technology Comparisons

Detection Sensitivity Detection probability statistics for Area 3 are summarized in Tables 11-14, and are summarized for all three sites in Table 15 which shows a comparison among the three demonstrators with data taken from the presentation of Dr. Cespedes at the ESTCP Workshop. NRL data are as turned in on-site, assuming 20-mm projectiles are not UXO. The absolute detection sensitivities of the NRL EM and magnetometer systems are similar. The EM sensors have a greater sensitivity for small shallow objects and the magnetometer array is more sensitive for large, more deeply buried objects. The EM sensors also detect small shallow objects more efficiently because, using the overlapping 1-meter coils, surface coverage approaches 100%. It is possible for small objects, such as 20-mm projectiles to pass between the magnetometers undetected, even with a 25-cm separation. Separations of 0.5-m or more would lead to more misses than detections for these small objects. To some extent, the detection sensitivity is also a function of target picking. Saturation picking will detect more metal objects, but without an efficient discrimination tool for analysis, many more objects will have to be dug using this approach. All three demonstrators appeared to have sufficient detection sensitivity to detect the full range of UXO items buried at the depths of this demonstration. The differences in detection efficiency of Surveyors B and C, relative to the *MTADS* is largely a matter of the number of targets chosen for declaration.

Table 15. Surveyor Performance at the JPG-V Demonstration*

Probability of UXO Detection

	NRL	*Surveyor B*	*Surveyor C*
Area 1	*95.3%*	*100%*	*90.7%*
Area 2	*96.7%*	*100%*	*93.3%*
Area 3	*100%*	*100%*	*90%*
Overall	*96.8%*	*100%*	*91.3%*

Objects Declared

Total Objects in Dig Sheet			
	NRL	*Surveyor B*	*Surveyor C*
Area 1	*149*	*177*	*144*
Area 2	*147*	*236*	*206*
Area 3	*142*	*202*	*105*

* This Table was adapted from Dr. Ernie Cespedes

Missed Targets Assuming that the sensors have sufficient sensitivity to detect these UXO challenges, the number of missed targets reflects three factors: the signal-to-noise and spatial resolution in the data, the number of targets chosen for declaration, and experience in extracting target signatures from geological and scrap clutter interferences in the data. While the EM sensors are much less subject to geological interferences from magnetic soils, the spatial resolution of the magnetometer sensors is significantly higher, allowing better unclustering of adjacent or nearby targets. This unclustering (or cleanup of complex target signatures) is a time consuming data processing step that does not readily lend itself to software automation. The time expended in this data cleanup is in part responsible for the accuracy of the *MTADS* in precisely locating and estimating sizes of UXO targets and in detecting deep targets in complex fields with nearby clustered targets. The relatively low EM coil sensitivity of the EMMS system used in the L-Range surveys led to both missed targets and relatively poor location accuracy. This has been overcome by the new EMMS system. The data from this man-portable unit is at least as high fidelity as the *MTADS* vehicular EM survey data.

Target Locations As described above, precision in location of targets is a strong function of data cleanup during analysis. However, our use of carefully time-stamped data, the highest precision GPS navigation systems, and high data sampling rates are equally critical in obtaining target data fits with sufficient information to precisely describe the target. In general, the location accuracy of the target fitting routines, from a vehicular *MTADS* magnetometer survey is about 10-15 cm while the EM array typically produces fits that are accurate to 15-25 cm. The lower accuracy is, in part due to the larger coil size of the EM array and the lower data density relative to the magnetometer data. The accuracy of the magnetometer fitting routines in predicting target depth are typically in the range of 20-30% of the absolute depth. Very shallow targets often have higher errors and deep targets are often fit to within 10% of their depth. The *MTADS* baseline EM fitting routine typically gives much poorer depth fitting accuracy than the magnetometer fitting algorithm. We have found that the 3-β fitting algorithm applied to EM data typically provides depth estimates that are more accurate than the baseline point-dipole EM fit, though they remain less accurate than the magnetometer depth predictions.

In Table 16 below, we compare the performance predictions of the vehicular *MTADS* magnetometer array, the MMS, and EMMS surveys with the JPG Ground Truth (provided by Ernie Cespedes for Area 3). To provide a greater range of information, we also independently compare the position and depth predictions of the MMS and EMMS surveys with the predictions resulting from the *MTADS* vehicular survey and analysis. The latter comparisons might reveal any systematic bias or significant random errors in the location accuracy of the provided ground truth.

The location and depth predictions of the vehicular *MTADS* survey compare favorably with the provided ground truth and fall within the expected accuracies of our system. There was neither any detectible systematic position bias, nor any significant single target location discrepancy. Likewise, the location accuracies and depth predictions of the MMS and EMMS surveys and analyses were within the expected accuracies of the systems. The performance of the MMS and the vehicular *MTADS* magnetometer array were statistically indistinguishable.

Table 16. Position and Depth Discrepancies Among the Magnetometer and EM Surveys Compared to the JPG Ground Truth*

Survey	ΔX-Y (m) Relative to JPG Ground Truth		ΔDepth (m) Relative to JPG Ground Truth		ΔX-Y (m) Relative to *MTADS* Mag		ΔDepth(m) Relative to *MTADS* Mag	
	Average	Median	Average	Median	Average	Median	Average	Median
EMMS	0.18	0.18	0.16	0.12	0.21	0.16	0.21	0.16
MMS	0.16	0.11	0.15	0.11	0.13	0.09	0.09	0.05
MTADS Vehicle Mag	0.16	0.09	0.13	0.08				

* Both UXO and Clutter Targets are included in this analysis.

Classification Performance Differentiating UXO from OE scrap and metallic clutter has been the primary objective of all our *MTADS* development programs for the past three years (except for the development of the man-portable *MTADS* adjuncts). We have participated in several ESTCP[17] and SERDP[24] programs (and have been cooperating and interacting with other development efforts) designed to create and evaluate data analysis approaches to improve UXO discrimination efficiency.

This test at JPG was the most stringent and comprehensive evaluation of the latest analysis tool for the EM system, the 3-β analysis algorithm.[17] The approach was originally developed for the *MTADS* EM array with the overlapping 1-meter coil systems. It was adapted for this development and this demonstration with the single unit 0.5-meter coil system. With the vehicular array we have typically conducted two orthogonal surveys of the same area to get the maximum possible shape information for the processor. In the present instance, the smaller coil provides higher resolution data, and because of it $0.5m^2$ total area, effectively radiates each object with a much wider range of incidence radiation vectors on each survey lane. Using the EMMS, we have taken data on closely spaced lanes to additionally assure overlap and high data density. Under these circumstances we have surveyed the three areas only once, and have used the processor to extract classification information. The classification results are shown in Table 17. Level 1 targets were most confidently assigned as UXO, level 2 are less so. Level 3 are doubtful, but more likely UXO, than not. Level 4 are declared as more likely not UXO. Level 6 is most likely not UXO, and we recommend that these targets do not need to be dug. Level 5, we feel is likely not UXO, but are not confident enough to leave them in the ground.

In this demonstration, we would describe the 3-β classifiers performance as a limited success. One classification metric is the ROC curve as presented by Dr. Cespedes at the ESTCP workshop. An adaptation of one of his tables is presented in Figure 25. These are plots of correct UXO declarations as a function of the number of non-UXO targets picked using the probability (increasing numerical confidence factor) as the running index. These plots show that Area 3 was

Table 17. Classification of the targets from the JPG surveys.*

Classification Confidence Level	AREA 1				AREA 2				AREA 3			
	3-β Analysis		Joint Analysis		3-β Analysis		Joint Analysis		3-β Analysis		Joint Analysis	
	20-mm	No 20-mm	20-mm	No 20-mm	20-mm	No 20-mm	20-mm	No 20-mm	20-mm	No 20-mm	20-mm	No 20-mm
1									22	18	20	17
2									17	6	15	9
3									14	11	25	14
4									12	8	13	8
5									28	19	42	21
6									41	72	39	85
Total Declarations									134	134	154	154
Dig/ Don't Dig									93/ 41	62/ 72	115/3 9	69/ 85

* Ground Truth Data were not available for Area 1 and 2 when this document was completed.

the easier site on which to classify targets. Reaching 90% correct UXO declarations on Area 3 required picking only about 60 non-UXO targets. On Area 1more than 80 targets had to be picked (and on Area 2 more than 90 targets had to be picked) to recover 90% of the seeded UXO.

A more stringent test of a target classifier is its ability to recognize OE scrap and metal clutter as metallic targets that can be left in the field. Considering Tables 11-14, using the 3-β classifier at the relatively benign Site 3, we correctly classified 11 of 29 or 21 of 34 OE scrap targets (depending upon whether 20-mm targets were included). This allowed us to correctly recommend leaving only 4 of 29 or 14 of 30 OE scrap targets in the field (again depending upon the presence of 20-mm UXO objects). In the ordnance column, we correctly classified 13 of 19, or 12 of 15 anomalies as UXO depending upon the disposition of the 20-mm projectiles. The 20-mm projectiles were the most difficult UXO targets to correctly classify.

Combining the EM and magnetometer survey data in a joint analysis improved both the classification and dig decisions by about a factor of two, while simultaneously decreasing the number of ordnance items that would be left in the field after digging. See Tables 13 and 14. The correct classification of UXO objects in the joint classification was similar to that using the EM data alone because these classifications were still primarily based upon the 3-β analysis. Most of the improvement in classification in the joint analysis was based upon the improved spatial resolution in the magnetometer data and the ability of the magnetic dipole analysis to recognize strong remnant moments.

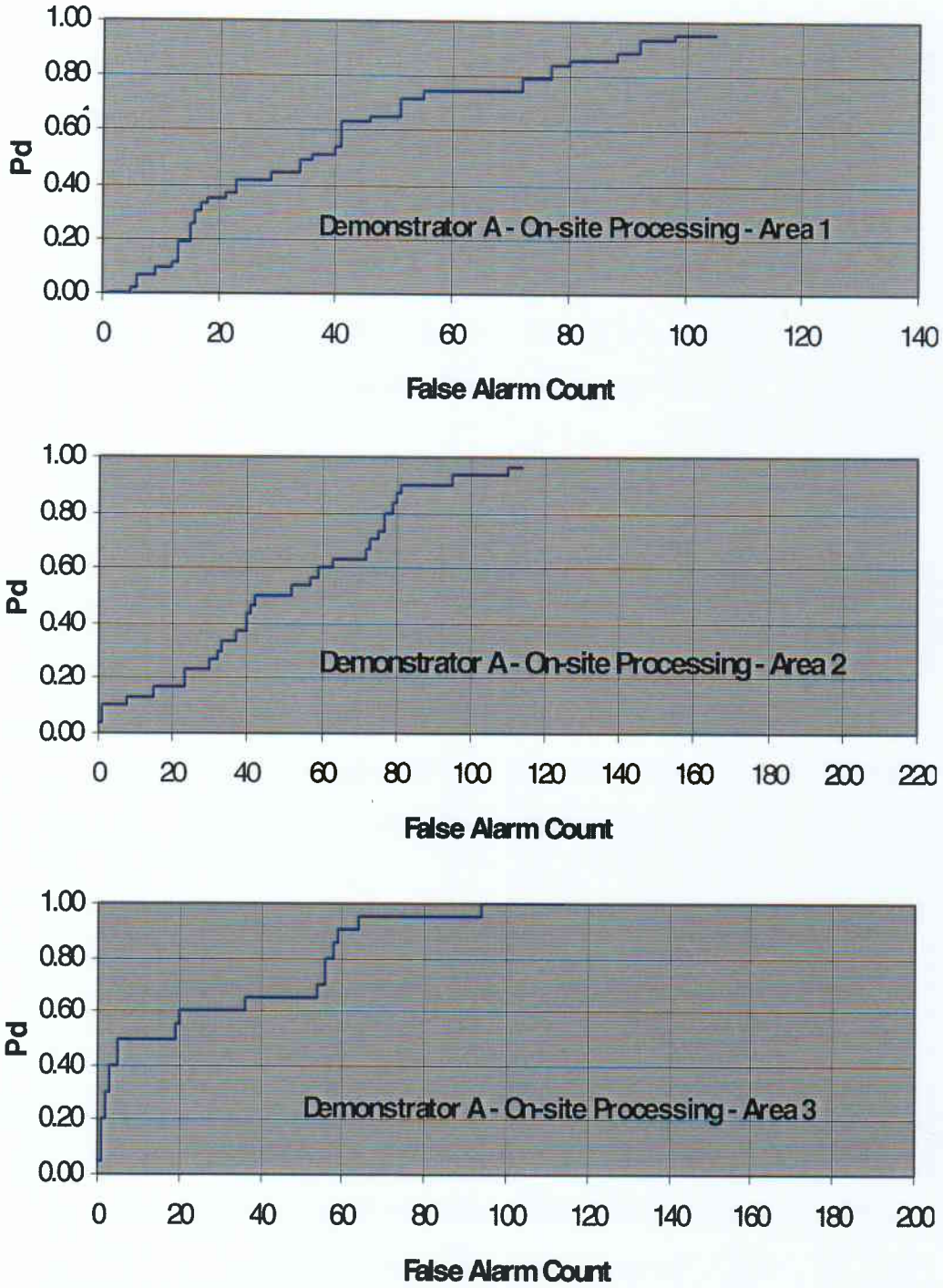

Figure 25. ROC curves for the EMMS survey and analysis of the three Demonstration Areas at the Jefferson Proving Ground. (Figure is adapted from Ernie Cespedes).

Where time and resources will allow, using both sensor platforms and a joint target analysis will provide improved target detection and recovery. It is problematical whether it will lower digging costs, overall. The improved classification capability in a joint analysis tends to be offset by the tendency to pick more targets using multiple survey data sets.

7.5 Cost and Production Rates

Assuming deployments similar to those at JPG-V, the *MTADS* deployment costs are about $10K per day, on site. The production rate of the MMS and EMMS system are about 1.5 hectares per day, in open areas using GPS navigation. The MMS can be used with less labor costs as it is much less labor intensive to operate. Production rates would likely decrease and costs would likely increase by a factor of 2-4 in difficult terrain or in a wooded environment. Production rates with the vehicular *MTADS* system are 7-10 hectares per day on areas with terrain typical of JPG. Vehicular production efficiencies are higher on larger sites because it is possible to use deployment strategies to more efficiently survey and analyze data. Daily, on-site, deployment costs are similar for the two systems. Mobilization costs are typically higher for the vehicular system because it requires leasing of a trailer truck and fuel and labor costs associated with transportation. In addition, in a commercial application, amortization or depreciation costs associated with the vehicular systems will be significantly higher for the vehicular system than for the man-portable adjuncts.

Without consideration of other complicating issues, deployment of the vehicular system to sites where it can be used is probably more efficient, if the sites are larger than 5 or 10 acres. For sites larger than 20 acres it would be difficult to rationalize use of the man-portable systems unless issues of availability arise, or if their use is required because of site logistics. Both the vehicular and the man-portable systems can be transported in the same trailer and could likely be simultaneously used, assuming the availability of the GPS equipment and the required labor to support simultaneous operations.

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