DEMONSTRATION REPORT- MOTLOW

Perform MetalMapper Classification Treatability Investigations as Part of Remedial Investigation/Feasibility Studies

ESTCP Project MR-201232

JULY 2014

Craig Murry
Parsons

Distribution Statement A

This document has been cleared for public release

Table of Contents

EXECUTIVE SUMMARY vi

1.0 INTRODUCTION 1
- 1.1 Background 1
- 1.2 Objectives of the Technology Demonstration 1

2.0 TECHNOLOGY 2
- 2.1 Technology Description 2
  - 2.1.1 Sensor Array 4
- 2.2 Application of the Technology 5
- 2.3 Advantages and Limitations of the Technology 5
  - 2.3.1 Advantages 6
  - 2.3.2 Disadvantages 6

3.0 PERFORMANCE OBJECTIVES 6
- 3.1 Global Positioning System/Robotic Total Station Accuracy 8
  - 3.1.1 Metric 8
  - 3.1.2 Data Requirements 8
  - 3.1.3 Success Criteria 8
- 3.2 EM61-MK2 Static Test Repeatability 8
  - 3.2.1 Metric 9
  - 3.2.2 Data Requirements 9
  - 3.2.3 Success Criteria 9
- 3.3 Correctly Locate Flag Positions 9
  - 3.3.1 Metric 10
  - 3.3.2 Data Requirements 10
  - 3.3.3 Success Criteria 10
- 3.4 Correctly Identify Seed Items in the Instrument Verification Strip 10
  - 3.4.1 Metric 10
  - 3.4.2 Data Requirements 10
  - 3.4.3 Success Criteria 11
- 3.5 Correctly Position Sensor Relative to Source 11
  - 3.5.1 Metric 11
  - 3.5.2 Data Requirements 11
  - 3.5.3 Success Criteria 11
- 3.6 Maximize correct classification of Targets of Interest 12
  - 3.6.1 Metric 12
  - 3.6.2 Data Requirements 12
  - 3.6.3 Success Criteria 12
- 3.7 Maximize Correct Classification of Non-Targets of Interest 12
  - 3.7.1 Metric 12
  - 3.7.2 Data Requirements 12
  - 3.7.3 Success Criteria 12
- 3.8 Correctly Identify Type of Targets of Interest 13
  - 3.8.1 Metric 13
  - 3.8.2 Data Requirements 13

3.8.3 Success Criteria ... 13
3.9 Correctly Identify Type of Non-Targets of Interest ... 13
3.9.1 Metric ... 13
3.9.2 Data Requirements ... 14
3.9.3 Success Criteria ... 14
3.10 Minimize Number of Anomalies That Cannot Be Analyzed ... 14
3.10.1 Metric ... 14
3.10.2 Data Requirements ... 14
3.10.3 Success Criteria ... 14
3.11 Correct Estimation of Target Location ... 14
3.11.1 Metric ... 14
3.11.2 Data Requirements ... 15
3.11.3 Success Criteria ... 15
3.12 Correctly Characterize the Site for Munitions and Explosives of Concern Nature and Extent ... 15
3.12.1 Metric ... 15
3.12.2 Data Requirements ... 15
3.12.3 Success Criteria ... 16

4.0 SITE DESCRIPTION ... 16
4.1 Site Selection ... 16
4.2 Site History ... 18
4.3 Site Geology ... 18
4.4 Munitions Contamination ... 18
4.5 Site Configuration ... 19

5.0 TEST DESIGN ... 19
5.1 Conceptual Experimental Design ... 19
5.2 Site Preparation ... 20
5.3 System Specification ... 20
5.4 Blind Seeding ... 20
5.5 Calibration Activities ... 21
5.6 Data Collection ... 21
5.6.1 Scale ... 21
5.6.2 Instrument Verification Strip Data Collection ... 21
5.6.3 Background Acquisition ... 22
5.6.4 Sample Density ... 22
5.6.5 TEMTADS System Parameters ... 22
5.6.6 Data Handling ... 22
5.6.7 Data Quality Checks ... 23
5.6.8 Intrusive Validation ... 23

6.0 DATA ANALYSIS AND PRODUCTS ... 25
6.1 TEMTADS Preprocessing ... 25
6.2 Parameter Estimation ... 25
6.3 Classifier and Training ... 25
6.3.1 Target Classification ... 28
6.3.2 Site Characterization ... 29

6.4 Data Products 30
6.4.1 Pre-Excavation Dig Lists 30

7.0 PERFORMANCE ASSESSMENT 31
7.1 Global Positioning System/Accuracy 31
7.2 EM61 Static Test Repeatability 31
7.3 Correctly Locate TEMTADS Flag Positions 31
7.4 Correctly Identify Seed Items in the Instrument Verification Strip 32
7.5 Correctly Position Sensor Relative to the Source 34
7.6 Maximize Correct Classification of Targets of Interest 36
7.7 Maximize Correct Classification of Non-Targets of Interest 38
7.8 Correctly Identify Type of Targets of Interest 38
7.9 Correctly Identify Type of Non-Targets of Interest 38
7.10 Minimize Number of Can't Analyze Targets 38
7.11 Correct Estimation of Target Parameters 39
7.12 Site Characterization 39
7.12.1 Type of Munitions and Explosives of Concern 39
7.12.2 Munitions and Explosives of Concern Density 39
7.12.3 Extent of Munitions and Explosives of Concern Contamination 39
7.12.4 Depth of Munitions and Explosives of Concern Contamination 40
7.12.5 Site Characterization Evaluation 40

8.0 COST ASSESSMENT 40
8.1 Cost Model 40
8.2 Cost Drivers 42
8.3 Cost Benefit 42

9.0 IMPLEMENTATION ISSUES AND LESSONS LEARNED 43

10.0 REFERENCES 43

Figures

Figure 2-1: Construction Details of an Individual TEMTADS Electromagnetic Induction Sensor 3
Figure 2-2: Individual Updated TEMTADS Electromagnetic Induction Sensor with Three-Axis Receiver....4
Figure 2-3: Sketch of the Electromagnetic Induction Sensor Array Showing the Position of the Four Sensors 4
Figure 2-4: TEMTADS MP 2x2 Cart Sensor Platform 5
Figure 3-1: EM61-MK2 and Static Test Item....9
Figure 4-1: Motlow Investigation Areas and Grid Locations. 17
Figure 4-2: Data Acquisition with the TEMTADS Sensor....19
Figure 5-1: Intrusive Operation Photos....24
Figure 6-1: TEMTADS Size-Decay Plot....27
Figure 7-1: Polarizability Curves Derived from Data Collected over Instrument Verification Strip Item 3 in the Morning (a) and Afternoon (b) of May 7, 2013 32
Figure 7-2: Receiver Operating Characteristic Curve for List 1....36
Figure 7-3: Inversion and Library Fit Results for Target 495 Using the a) Single Object and b) Multi-Object Methods 37
Figure 7-4: Receiver Operating Characteristic Curve for List 2....38

Tables

Table 3-1 Performance Objectives for this Technology Demonstration 6
Table 5-1 Instrument Verification Strip Items 22
Table 5-2 TEMTADS Acquisition Parameters Used at Motlow 22
Table 6-1 Categories for Motlow Cued Targets 28
Table 6-2 Ranked Dig List Summary Statistics....31
Table 7-1 Instrument Verification Strip Data Point with Low Weighted Metrics....32
Table 8-1 Details of the Costs That Will Be Tracked....41

Acronyms

β1, β2, β3	polarizabilities along principal axes of target
μs	microsecond(s)
AOL	Advanced Ordnance Locator
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
DoD	Department of Defense
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
ID	identification
ISO	industry standard object
IVS	instrument verification strip
kHz	kilohertz
MD	munitions debris
MEC	munitions and explosives of concern
mm	millimeter
Motlow	Motlow Range Complex
MP	man-portable
MPV	Man-Portable Vector
MR	munitions response
MRS	munitions response site
ms	millisecond(s)
Parsons	Parsons Government Services, Inc.
QC	quality control
RI/FS	remedial investigation and feasibility study
RTK	real-time kinematic
RTS	Trimble Robotic Total Station
TOI	targets of interest
USACE	U.S. Army Corps of Engineers
UXO	unexploded ordnance

EXECUTIVE SUMMARY

Parsons Government Services, Inc. (Parsons) performed this project as a contractor to the Environmental Security Technology Certification Program (ESTCP) under contract W912HQ-12-C-0007, MR-201232. This contract was established to perform a technology demonstration of advanced geophysical sensors such as the Naval Research Laboratory's TEMTADS Man-Portable (MP) 2x2 Cart at munitions response sites (MRSs) such as the Motlow Range Complex (Motlow) as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial investigation and feasibility study (RI/FS) process.

This report describes in detail the procedures, methods, and resources Parsons used to complete the technology demonstration at the Motlow Range Complex. The technology demonstration was conducted with two major objectives:

- Accurately classify each of the collected targets as either a target of interest (TOI), likely representing a munition or explosive concern (MEC), or non-TOI, representing another type of anomaly source such as munition fragments or other metallic clutter.
- Evaluate the use of classification technology for MEC site characterization.

To accomplish these objectives, Parsons demonstrated the use of one of the advanced geophysical sensors, the TEMTADS, as part of the RI/FS project at Motlow. During the RI field work, traditional digital geophysical mapping was performed over approximately 19 acres of the site using an EM61-MK2 (EM61), and the technology demonstration mapped 6.25 of the 19 acres to test the TEMTADS sensor and the advanced classification process. Data were collected over a total of 903 anomalies in May and June 2013. Of the 903 targets, only 794 targets were intrusively investigated because one landowner revoked the right of entry.

The data collected were inverted and analyzed using the UX-Analyze add-on to Geosoft's Oasis montaj software. Each target was then classified as either a TOI or non-TOI using two classification schemes (one aggressive and one conservative) developed based on the results of the prior classification demonstration projects and the TOI expected at the Motlow site. The ranked dig lists were prepared based on these results, with the targets most likely to be TOI at the top and the targets most likely to be clutter at the bottom. Those classified as TOI and any targets that could not be analyzed based on the data collected were identified as "dig" targets; those classified as non-TOI were identified as "no-dig" targets. The aggressive list identified 312 "dig" targets out of the 903 classified targets (35%). The conservative list identified 417 "dig" targets, 46% of the classified targets.

The intrusive investigation of these targets was completed June 31, 2013. Preliminary dig list scoring was based on the number of TOI correctly identified as items that should be dug and the number of non-TOI or clutter items that were correctly classified as items that did not need to be intrusively investigated. Comparison of the aggressive dig list with this ground truth set resulted in the correct identification of more than 98% of the TOI on site (one TOI incorrectly classified as clutter) and a 70% reduction in clutter that would have been dug, while the more conservative list correctly identified all of the TOI on site with a 57% reduction in clutter digs.

1.0 INTRODUCTION

Parsons Government Services, Inc. (Parsons) performed this project as a contractor to the Environmental Security Technology Certification Program (ESTCP) under contract W912HQ-12-C-0007, MR-201232. This contract was established to perform a technology demonstration of advanced geophysical sensors such as the Naval Research Laboratory's (NRL) TEMTADS Man-Portable (MP) 2x2 Cart at munitions response sites (MRSs) such as the Motlow Range Complex (Motlow) as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial investigation and feasibility study (RI/FS) process.

Currently, up to 90% of excavation costs on most munitions and explosives of concern (MEC) projects are related to removing scrap metal that does not represent an explosive hazard. Significant cost savings could be achieved through the use of geophysical classification methods that could reduce the number of excavations required to remove explosive hazards from sites. Over the past 6 years, ESTCP has been demonstrating these technologies at active and formerly used defense sites across the country to determine the effectiveness of advanced electromagnetic induction (EMI) sensors in classifying subsurface metal as either a target of interest (TOI), which potentially represents MEC that should be intrusively investigated, or as clutter that could be left in the ground without further investigation. This report presents the results from the technology demonstration performed at the Motlow Range Complex, near Tullahoma, TN.

1.1 BACKGROUND

The fiscal year 2006 defense appropriation contained funding for the "Development of Advanced, Sophisticated Discrimination Technologies for Unexploded Ordnance (UXO) Cleanup." ESTCP responded by conducting UXO discrimination studies at sites across the country that were potentially contaminated with MEC. Investigated sites have included Camp Sibert, AL; Camp San Luis Obispo, CA; Camp Butner, NC; the Pole Mountain Target and Maneuver Area, WY; Fort Sill, OK; Spencer Artillery Range, TN; Camp Beale, CA; and the subject site at Motlow Range Complex, TN. Target munitions at these sites have included various types of munitions ranging in size from 30-millimeter (mm) projectiles to 4.2-inch mortars; munitions included mortars, rockets, hand grenades, rifle grenades, fuzes, and many types and sizes of projectile. The results of these investigations have been very encouraging, with demonstrators correctly identifying the vast majority of the TOI at each site while reducing the amount of unnecessary digs on non-TOI targets by up to 90%.

To build upon the success of these studies, ESTCP demonstrated one of the advanced technologies, the TEMTADS, as part of the RI/FS project at Motlow. A traditional digital mapping survey was performed with the EM61-MK2 (EM61) sensor at Motlow before the demonstration study to locate anomalies. The technology demonstration was conducted over 903 of those anomalies.

1.2 OBJECTIVES OF THE TECHNOLOGY DEMONSTRATION

Cued (i.e. static) TEMTADS data were collected over approximately 903 geophysical targets out of the 2,081 anomalies identified in EM61 data collected for the Motlow RI. The first objective of the TEMTADS data collection and analysis was to accurately classify each of the collected

targets as either a TOI or non-TOI. The results of this technology demonstration will be incorporated into the FS report, and a remedial alternative involving the TEMTADS may be evaluated in the FS. The second objective of the technology demonstration was to evaluate the use of classification technology for MEC site characterization. This evaluation included comparing the TEMTADS data from Motlow with data collected at other sites for which ground truth data were available to determine if the same site characterization conclusions could be reached with limited intrusive investigation.

Specific performance objectives were developed for the technology demonstration. In addition to the correct classification of TOI, these included the following:

- Maximize the percentage of non-TOI items left in the ground.
- Correctly identify the types of TOI prior to intrusive investigation.
- Correctly identify the general type of non-TOI (e.g., fragment, horseshoe, farm equipment) prior to intrusive investigation.
- Minimize the number of targets classified as "can't analyze."
- Correctly estimate target parameters such as location and depth.
- Correctly characterizing the nature and extent of MEC contamination at the site.

Additional detail regarding the performance objectives identified for the project is contained in Section 3.0.

1.3 REGULATORY DRIVERS

As part of the cleanup of former Department of Defense (DoD) sites, buy-in is required from regulatory agencies at the federal, state, and local levels. The advancement in classification sensors and their successful deployment at real-world sites needs to be documented for their use to be accepted by the applicable regulatory agencies. Their acceptance of the use of this technology at sites for which they are ultimately responsible will be particularly important with the potential for DoD budget cuts to reduce the amount of money available for future remedial actions.

The Motlow RI/FS technology demonstration integrated the advanced classification work into the Comprehensive Environmental and Response, Compensation and Liability Act (CERCLA) process for site characterization and remedial alternative selection. Involving regulatory agencies and other stakeholders in the demonstration was intended to facilitate their acceptance of advanced classification technologies.

2.0 TECHNOLOGY

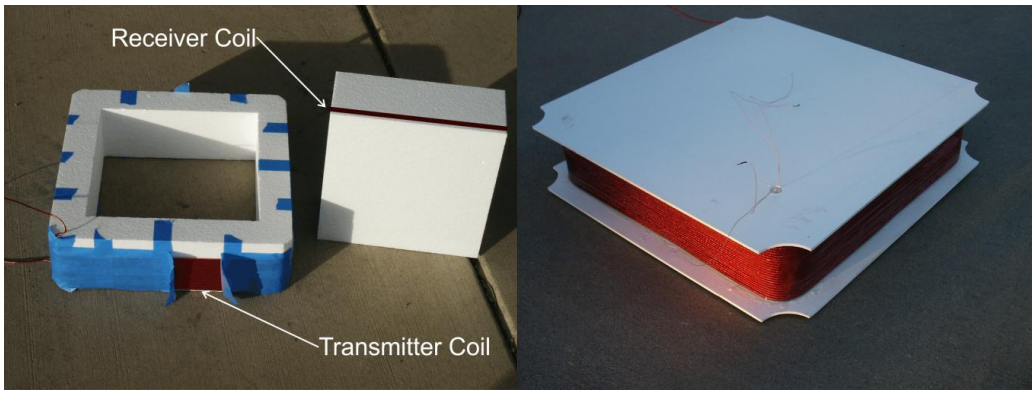
2.1 TECHNOLOGY DESCRIPTION

The EMI sensor used in the TEMTADS array is based on the Navy-funded Advanced Ordnance Locator (AOL), developed by G&G Sciences. The AOL consists of three transmit coils arranged in a 1-meter cube. The TEMTADS has adopted the transmit (Tx) and receive (Rx) subsystems of this sensor directly, converted to 35-centimeter (cm) square sensors that can be assembled in a

variety of array configurations, and made minor modifications to the control and data acquisition computer to make it compatible with our deployment scheme.

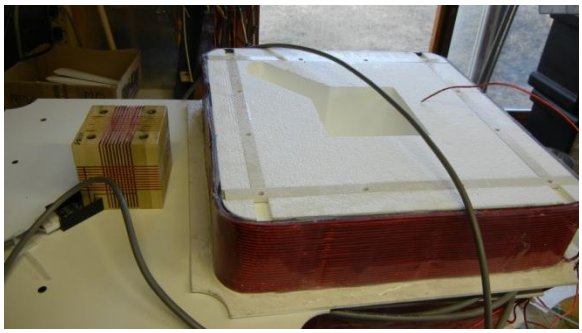
A photograph of a standard TEMTADS sensor element (as used in ESTCP Munitions Response [MR] Project MR-200601 array) under construction is shown in the left panel of Figure 2-1. The transmit coil is wound around the outer portion of the form and is 35 cm on a side. The 25-cm receive coil is wound around the inner part of the form, which is reinserted into the outer portion. An assembled sensor with the top and bottom caps used to locate the sensor in the array is shown in the right panel of Figure 2-1.

Figure 2-1: Construction Details of an Individual TEMTADS Electromagnetic Induction Sensor



In addition to the TEMTADS 5x5 array developed under ESTCP MR-200601, the TEMTADS MP 2x2 Cart system was designed and built using the same sensor elements. Demonstration of the MP system at the Aberdeen Test Center Standardized UXO Test Site in August, 2010, indicated need for revision of the sensor technology for the MP system to collect sufficient data over an anomaly. A modified version of the sensor element was designed and built, replacing the single, vertical receiver loop of the original coil with a three-axis receiver cube. These receiver cubes are identical in design to those used in the AOL2 and Geometrics MetalMapper (ESTCP MR-200603) system, with dimensions of 8 cm rather than 10 cm. The Cold Regions Research and Engineering Laboratory man-portable vector (MPV) MPV2 system (ESTCP MR-201005) uses an array of five similar receiver cubes and a circular transmitter coil. The new sensor elements are designed to have the same form factor as the originals, aiding in system integration. A new coil under construction is shown in Figure 2-2.

Figure 2-2: Individual Updated TEMTADS Electromagnetic Induction Sensor with Three-Axis Receiver



Decay data are collected with a 500-kilohertz (kHz) sample rate until 25 milliseconds (ms) after turn-off of the excitation pulse. This results in a raw decay of 12,500 points; too many to be used practically. These raw decay measurements are grouped into 121 logarithmically-spaced "gates" with center times ranging from 23 microseconds (μs) to 24.35 ms with 5% widths and are saved to disk.

2.1.1 Sensor Array

The TEMTADS consists of four individual EMI sensors with three-axis receivers, arranged in a 2 x 2 array as shown in Figure 2-3. The center-to-center distance is 40 cm, yielding an 80 cm x 80 cm array. A picture of the array mounted on the TEMTADS MP 2x2 Cart platform is shown in Figure 2-4.

Figure 2-3: Sketch of the Electromagnetic Induction Sensor Array Showing the Position of the Four Sensors

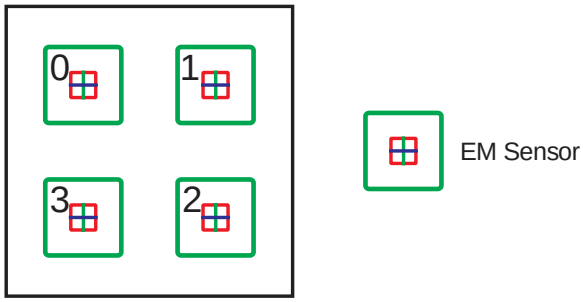


Figure 2-4: TEMTADS MP 2x2 Cart Sensor Platform

2.2 APPLICATION OF THE TECHNOLOGY

The first step of applying advanced classification sensors in static mode is detecting geophysical anomalies possibly caused by buried TOI and developing a list of their coordinates. For the Motlow technology demonstration, the anomaly list was created using the EM61 data collected as part of the RI. Each anomaly from the list was reacquired, and a plastic pin flag was placed at its location prior to the demonstration, allowing the TEMTADS to be centered over each flag. When positioned over the target, the array sensors are fired sequentially, and decay data are collected from all 12 receive coils for each excitation. These data are then stored electronically on the data acquisition computer. Before moving to the next target, the operator evaluated a display of the four monostatic, z-axis (vertical) signal amplitudes at the first time gate (71 μs) and compared the values to a low signal-to-noise ratio threshold (nominally 5 millivolts per ampere). If no amplitude was above the threshold, the operator could elect to collect additional data for the target before leaving the target location. The data were transferred to a laptop computer and transmitted to an offsite analyst for processing at the end of each day.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Several previous demonstration projects have evaluated and documented the advantages and limitations of the specific sensor used for the Motlow RI/FS technology demonstration, the TEMTADS 2x2 (ESTCP, 2011; ESTCP, 2013). The technology demonstrated as part of this project is more generally advanced classification rather than a specific geophysical sensor. The advantages and limitations of advanced classification are listed below.

2.3.1 Advantages

- Advanced classification can be used to determine which targets are related to TOI. These results allow a project team to reduce the number of targets that must be intrusively investigated to reduce the explosive hazard at a contaminated site and thus reduce the overall cost of the project.
- By using advanced classification to reduce the number of excavations, the project team can reduce the impact to the community by not requiring evacuations or limiting access to areas close to intrusive investigations of potential MEC.
- Limiting the number of excavations also reduces the physical impact on the site that may have adverse effects on plant/animal habitat or residents' property.

2.3.2 Disadvantages

- Advanced classification is an emerging technology that has been implemented at a limited number of sites.
- Regulatory agency personnel are not as familiar with the advanced classification technology as they are with more mature geophysical technologies such as the EM61 sensor.
- Advanced classification results are less reliable in areas with very high anomaly density (e.g., in the very center of a target area).
- A limited number of personnel are qualified to collect and analyze advanced classification data, restricting the number of contractors qualified to perform projects with advanced classification.
- Advanced classification sensors are not as field rugged as standard geophysical sensors.
- A limited number of advanced classification sensors are available to be used on production projects.
- Collecting and analyzing advanced sensor data can require more effort than EM61 or magnetic detection data, increasing the survey costs.

3.0 PERFORMANCE OBJECTIVES

The data collection and analysis performance objectives for this demonstration are summarized in Table 3-1.

Table 3-1: Performance Objectives for this Technology Demonstration

Performance Objective	Metric	Desired Level (Objective)	Success Criteria
Reacquisition Objectives			
GPS/RTS accuracy	Difference between measured and known monument locations	100% of tests within 10 cm of expected location	100% of tests within 10 cm of expected location
EM61 static test repeatability	Difference between measured Ch2 response and standard Ch2 response	100% of tests within +/- 10% of standard	100% of tests within +/- 10% of standard

Table 3-1: Performance Objectives for this Technology Demonstration (Continued)

Performance Objective	Metric	Desired Level (Objective)	Success Criteria
Correctly locate flag locations	Location of placed flag relative to dynamic EM61 target	All flagged locations > 30 cm from picked location will be resurveyed; flagged locations > 73 cm from picked location will be flagged at both picked and reacquired locations	All flagged locations > 30 cm from picked location will be resurveyed; flagged locations > 73 cm from picked location will be flagged at both picked and reacquired locations
Data Collection/Processing Objectives			
Correctly identify seed items in IVS strip	Percentage of IVS items identified correctly	100% of IVS items identified correctly with confidence metric of > 0.7	98% of IVS items identified correctly with confidence metric of > 0.7
Correctly position sensor relative to source	Distance between collection location and inverted target location	100% of inverted locations within 40 cm of collection point unless re-shot also outside radius[1]	100% of inverted locations within 40 cm of collection point unless re-shot also outside radius[1]
Analysis and Classification Objectives			
Maximize correct classification of targets of interest	Percentage of TOI retained.	100% of TOI classified correctly	98% of TOI classified correctly
Maximize correct classification of non-TOI	Percentage of false alarms eliminated.	75% of non-TOI left in ground	60% of non-TOI left in ground
Correctly identify type of TOI	Percentage of TOI correctly identified by group[2]	95% of TOI indentified correctly	75% of TOI identified correctly
Correctly identify type of non-TOI	Percentage of non-TOI correctly identified by group[3]	95% of non-TOI indentified correctly	50% of non-TOI identified correctly
Minimize number of Can't Analyze targets	Percentage of targets that cannot be classified due to questionable data	Less than 5% of points indentified as Can't Analyze	Less than 15% of points indentified as Can't Analyze
Correct estimation of target location	Accuracy of estimated target parameters for dig list targets marked as "dig"[4]	X, Y < 20 cm (1σ) Z < 10 cm (1σ)	X, Y < 30 cm (1σ) Z < 15 cm (1σ)
Correctly characterize the site for MEC nature and extent	Consistency of characterization conclusions based on classified data and intrusive results	100% consistent conclusion with +/- 25% agreement on numerical conclusions[5]	Only one inconsistent conclusion

[1] EM61 targets were reacquired using an EM61 for the first 81 anomalies; flags were placed at the peaks of identified anomalies. If the reacquired peak was greater than 30 cm from the picked location, the revised target location was collected using the RTK GPS.

[2] Groups for TOI were small (37 mm, small industry standard object [ISO]), medium (57-mm projectiles, 60-mm mortars, and medium ISOs) and large (81-mm mortars, 105-mm projectiles, large ISOs, and any larger TOI)

[3] Groups for non-TOI were small and cylindrical, large and cylindrical, small and plate-like, and large and plate-like.

[4] Performance objectives for horizontal locations are less accurate than typical because the TEMTADS was used without GPS equipment and the reacquire flag locations may be moved up to 30 cm to the peak of the EM61 anomaly without updating the coordinate associated with the flag.

[5] Numerical conclusions included MEC density and the depth estimates.

3.1 GLOBAL POSITIONING SYSTEM/ROBOTIC TOTAL STATION ACCURACY

A real-time kinematic (RTK) global positioning system (GPS) was used to identify the locations of the previously selected EM61 targets. The RTK GPS was tested daily at an existing survey control point that was located on Motlow State Community College campus grounds to ensure that it was accurately measuring these locations.

3.1.1 Metric

The metric for this objective was the offset between the location of a point measured by the GPS and the known location of that point.

3.1.2 Data Requirements

The GPS was used to measure the location of a known point once on each day that it was used during the project. The operator recorded the name and the known and measured locations of the point being tested in the RTK GPS unit.

3.1.3 Success Criteria

The performance objective for the project was for the all locations measured by the GPS to be within 10 cm of the expected locations for each test. Any problems identified following data collection would be diagnosed to determine if the resurvey of any points is necessary. Problems and solutions would be documented following the performance of a root-cause analysis.

3.2 EM61-MK2 STATIC TEST REPEATABILITY

An EM61 was used to position the pin flags used to guide the TEMTADS cued survey and to confirm intrusive investigations were complete. EM61 quality control (QC) testing was accomplished via a static tests performed using a standard test item, in this case a small industry standard object (ISO) attached to a polyvinyl chloride pipe that was laid across the EM61 coil (Figure 3-1). Data were collected without the test item and then with the item in the center of the coil. The response for the test item was defined as the measured reading with the ISO in the coil minus the measured reading without the ISO present.

Figure 3-1: EM61-MK2 and Static Test Item

3.2.1 Metric

The metric for this objective is the difference between the EM61 channel 2 response over a small ISO during the daily testing and the expected response for the ISO.

3.2.2 Data Requirements

Static tests were performed with the EM61 twice each day, before and after use. Data were collected for 180 seconds with no test item, for 60 seconds with a small ISO jig placed on the coil, and for another 60 seconds with no test item. The measured response was calculated by subtracting the average response recorded for channel 2 for the first line (no test item) from the average response recorded for channel 2 for the second line (ISO measurement). The measured response was compared to the standard, expected response recorded at the outset of the project.

3.2.3 Success Criteria

The performance objective for the project was for the all measured responses to be within +/- 10% of the expected response. Problems and solutions are typically documented by performing a root-cause analysis.

3.3 CORRECTLY LOCATE FLAG POSITIONS

After the picked location of one of the targets selected in the dynamic EM61 survey was identified using the GPS, the field crew used an EM61 to refine the location of the peak of the anomaly generated by the target. A pin flag was then placed at the peak identified during reacquisition for later survey with the TEMTADS. Because all TEMTADS locations were reported relative to a local coordinate system with an origin on the collected point, the location of the collected point was particularly important for this project. Therefore, points with

significant offset between the picked EM61 target and the flagged location were identified and the refined location remeasured.

3.3.1 Metric

The metric for this objective was the offset between the EM61 target selected in the dynamic data set and the refined location as determined during reacquisition.

3.3.2 Data Requirements

The EM61 was used to refine the location of the first 81 reacquired targets. The reacquired peak locations for 18 of those targets were greater than 30 cm from the picked target location. Those reacquired peak locations were resurveyed using the GPS, and the original target location was replaced with the updated location in the project database.

This process was changed after reacquiring the first 81 anomalies. For the remaining reacquisition work, the originally selected target locations were marked in the field. The TEMTADS field inversion was used to confirm that the instrument was over the source of the anomaly, and additional data points were collected over the field inverted location of the object if it was further than 30 cm from the originally selected target location.

3.3.3 Success Criteria

All flags were to be placed within 30 cm of the initial picked location, or the refined location was to be resurveyed. Offsets less than 30 cm were not to be recorded, and target coordinates were to be updated in or added to the project database as necessary. All TEMTADS collection points were assumed to be the location specified in the project database.

3.4 CORRECTLY IDENTIFY SEED ITEMS IN THE INSTRUMENT VERIFICATION STRIP

One instrument verification strip (IVS) was established on the Motlow State Community College property in an area with geologic and soil properties that were similar to what was expected for the MRS. The strip contained two small ISO items. Two additional ISOs were located due west of the IVS strip. This allowed the TEMTADS to collect QC data over multiple items (four in total). TEMTADS data were collected over these four items at least twice daily each day the instruments were used.

3.4.1 Metric

The metric for this objective is the percentage of IVS items correctly classified with confidence metrics above 0.7 during the project.

3.4.2 Data Requirements

Daily IVS data were collected and processed in the same manner as all other target points acquired during the project. Following analysis, each IVS target was labeled with an identified source object and a confidence metric that quantified the degree of match between three polarization curves ($\beta 1$, $\beta 2$, and $\beta 3$) generated from the measured IVS data and three polarization curves for a similar item in a target library. For the IVS, the confidence metric used for classification purposes was generated using $\beta 1 : \beta 2 : \beta 3$ ratios of 1 : 0.5 : 0.5.

3.4.3 Success Criteria

The performance objective for the project was the correct classification of all IVS seed items with a confidence metric of 0.70 or higher. However, the occasional collection of a poor data point without the operator's immediate knowledge was a possibility, so project-wide IVS results would be deemed successful if more than 98% of the IVS data points were classified correctly. Identification of specific IVS items was performed according to the groups used for TOI identification. Proposed groups were based on the size of the TOI and seed items expected at the site, including 37-mm projectiles, 60-mm mortars, 81-mm mortars, 4.2-inch mortars, 10-mm projectiles, and 155-mm projectiles. The small group covers both 37-mm projectiles and small ISOs, the medium group covers 60-mm projectiles and medium ISOs, and the large group covers 81-mm mortars, 105-mm projectiles, large ISOs, and any larger munitions.

3.5 CORRECTLY POSITION SENSOR RELATIVE TO SOURCE

High-fidelity estimates of a target's principal polarizability curves depend on adequate illumination of the target along each of its principal axes. Targets with horizontal offsets of 40 cm or more from the center of the TEMTADS are not adequately illuminated, and thus their symmetry properties are sometimes not apparent. While the goal was to place each sensor directly on top of the source item, adjacent targets and geologic conditions can result in modeled or fit locations for the source object a significant distance from the collection point.

3.5.1 Metric

The metric for this objective was the distance between the location of the sensor for a given point and the modeled location for the source object following inversion.

3.5.2 Data Requirements

TEMTADS data location uses a local coordinate system that defines the center of the array during collection as 0x, 0y. All translation to the project coordinate system was performed using either the picked location of a given target from the dynamic EM61 survey (< 30 cm offset during reacquisition) or the reacquired location of the target (> 30 cm offset during reacquisition). The location of the source object was calculated during inversion of the collected data and was identified in terms of an offset from the center of the array (0x, 0y). The location of the source object was defined by the Fit_X[14] and Fit_Y[14] channels in the Geosoft target database.

3.5.3 Success Criteria

The objective was for all targets to have modeled source locations within 40 cm of the center of the sensor. Targets that did not meet this criterion were identified for re-collection. Re-collection locations were at the inverted target location from the first shot unless the inversion located the source near another target. Targets with inverted locations essentially on top of another target were not re-collected. If the distance between the sensor and the modeled location of the source was greater than 40 cm for the re-shot as well, data collection for that point was considered successful.

3.6 MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

One of the main objectives of this technology demonstration was to show that classification could correctly identify all seeded items and any MEC items remaining at the site as TOI.

3.6.1 Metric

The metric for this objective was the percentage of items classified as TOI following the intrusive investigation that were correctly identified as objects that should be dug in the final ranked dig list.

3.6.2 Data Requirements

Following data collection, TEMTADS data was analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI 2) non-TOI, or 3) Can't Analyze. The targets classified as either TOI or Can't Analyze were considered "dig" targets. The list of items identified as TOI following the completion of intrusive operations, including seed items, was compared to those targets marked "dig" in the ranked dig list.

3.6.3 Success Criteria

The performance objective for the correct identification of all TOI (including blind seed items) was to identify all TOI for intrusive investigation or as "dig" targets. The project will be deemed successful if 98% of the TOI are labeled as "dig" targets in the final ranked dig list. No distinction was made between a target correctly identified as TOI and a target identified as a Can't Analyze point for this objective. Each TOI simply needed to be indicated as a target that should be investigated.

3.7 MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

This is the second of the two primary measures of the effectiveness of the classification approach. In addition to correctly classifying TOI, the effectiveness of the TEMTADS in discriminating munitions is a function of the degree to which responses that do not correspond to TOI can be eliminated from consideration during the intrusive investigation.

3.7.1 Metric

The metric for this objective was the percentage of items classified as non-TOI following the intrusive investigation that were correctly identified as objects that did not need to be intrusively investigated in the final ranked dig list.

3.7.2 Data Requirements

The list of items identified as non-TOI following the completion of intrusive operations was compared to those targets marked "no dig" in the ranked dig list.

3.7.3 Success Criteria

The performance objective was to correctly label more than 75% of the non-TOI items as non-TOI while retaining at least 98% of the TOI (Section 3.6) above the dig threshold. The project

would be deemed successful if at least 60% of the non-TOI items could be removed from the list of targets designated for intrusive investigation.

3.8 CORRECTLY IDENTIFY TYPE OF TARGETS OF INTEREST

In addition to correctly classifying each TOI as a target that needs to be intrusively removed, there is value in being able to correctly specify what the target is before digging commences. Forehand knowledge regarding the size or type of TOI could have significant impacts on considerations such as the number of nearby residents that may need to be evacuated before an item is removed from the ground. While this are not a significant concern at Motlow, the ability to correctly identify TOI is worth documenting for future projects. It also provides confidence that the classification process is working as intended for quality assurance purposes.

3.8.1 Metric

The metric for this objective is the percentage of TOI items that are assigned to the correct group in the dig list. The groups are described below.

3.8.2 Data Requirements

Each target identified as a TOI for the later intrusive investigation was labeled with the type of TOI it most likely represented following the final classification of each. The identification for each was assigned based on the closest match to that item in the classification library. After an initial identification had been made, the item was assigned to one of three groups: small, medium, and large. The small group covers 37-mm projectiles, small ISOs, and any other TOI similar in size to a 37-mm projectile. The medium group covers 57-mm projectiles, 60-mm mortars, medium ISOs, and any other TOI with diameters between 57-mm and less than 75-mm. The large group covers 75-mm projectiles, 81-mm mortars, 105-mm projectiles, and any other TOI with a diameter greater than 75-mm. Identifications will be compared to the final dig results for each piece of TOI.

3.8.3 Success Criteria

The performance objective was to assign more than 95% of the TOI items to the correct group. The project was deemed successful if at least 75% of the TOI items were placed into the correct group.

3.9 CORRECTLY IDENTIFY TYPE OF NON-TARGETS OF INTEREST

While the identification of non-TOI does not generally affect dig operations the way that the identification of TOI might, it could still play an important role in convincing stakeholders that the items being left in the ground are being left there for a reason.

3.9.1 Metric

The metric for this objective was the percentage of intrusively investigated non-TOI items that were assigned to the correct group in the dig list. The groups are described below.

3.9.2 Data Requirements

Each target identified as a non-TOI for the intrusive investigation was labeled with the type of non-TOI it most likely represented following the final classification of each. The size and symmetrical properties of the final inversion results were used to assign each non-TOI target to one of four groups. The four groups were small and cylindrical, large and cylindrical, small and plate-like, and large and plate-like.

3.9.3 Success Criteria

The performance objective was to assign more than 95% of the non-TOI items investigated to the correct group. The project would be deemed successful if at least 50% of the non-TOI items were assigned to the correct group. Non-TOI items incorrectly marked as "dig" targets in the dig list (i.e., false alarms) were not included in this analysis. Rather, specific examples of targets classified as non-TOI were intrusively investigated to compare results.

3.10 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated using the collected TEMTADS data cannot be classified. These anomalies must be placed in the dig category, which reduces the effectiveness of the classification process.

3.10.1 Metric

The percentage of anomalies for which reliable parameters could not be estimated was the metric for this objective.

3.10.2 Data Requirements

Those targets for which parameters could not be reliably estimated were identified as such on the prioritized dig list submitted following analysis of the TEMTADS data.

3.10.3 Success Criteria

The performance objective was to estimate reliable parameters for greater than 95% of the targets on the prioritized dig list. The project would be deemed successful if reliable parameters could be estimated for more than 85% of the targets.

3.11 CORRECT ESTIMATION OF TARGET LOCATION

This objective involves the accuracy of the modeled location for target source objects. The correct estimation of the location, both horizontally and vertically, increases confidence in both the dig team and stakeholders that the correct source object is being investigated if the estimated location is relatively close to the recovered object's location.

3.11.1 Metric

The distance between the inverted target location and the location of the object(s) recovered during the intrusive investigation was the metric for this objective.

3.11.2 Data Requirements

The dig list submitted to the intrusive team contained X,Y locations for each target as determined during inversion of that target. The dig teams measured the position of all recovered items with RTK GPS equipment. The offset between the modeled location and the actual locations were compared following the completion of the project.

3.11.3 Success Criteria

The project objective would be considered to be met if one standard deviation (1σ) of the distance between the estimated X, Y locations and the recovery locations was less than 20 cm and the estimated depths are within 10 cm (1σ). The project would be deemed successful if the standard deviations were within 30 cm horizontally and 15 cm vertically. The estimated item locations were expected to be less accurate for the TEMTADS because no GPS equipment was used during TEMTADS data collection. The estimated item locations were based on an offset from the location flagged during reacquisition.

3.12 CORRECTLY CHARACTERIZE THE SITE FOR MUNITIONS AND EXPLOSIVES OF CONCERN NATURE AND EXTENT

This objective involves the comparison of the TEMTADS data from Motlow with results from other sites containing similar types of MEC. Separate interpreters characterized the site for the nature and extent of MEC contamination based on 1) all intrusive data collected during the RI and 2) the TEMTADS classification data and a limited quantity of intrusive results.

3.12.1 Metric

The site characterization conclusions based on the intrusive results will be considered correct. The classification-based conclusions will be evaluated to determine how well they match with the conclusions based on all the intrusive results.

3.12.2 Data Requirements

The intrusive results from all anomalies and the anomaly density map produced from the EM61 transect surveys are used to establish the baseline conclusions about the nature and extent of MEC contamination. These conclusions include the following:

- Type of MEC present in different parts of the site
- MEC density across the site
- Extent of MEC contamination
- Depth of MEC contamination

For the classification-based site characterization effort, the TEMTADS data are used, but only a limited amount of intrusive data are considered. The analyst evaluated the classification results and determined which anomalies would provide the most useful data for the classification. Data collected at other sites with similar types of MEC are also used to classify the types of MEC present at the site. The number of intrusive results requested by the classification site characterizer will be an important factor in determining if classification is a cost-effective tool for RI/FS projects.

3.12.3 Success Criteria

The performance objective was considered to be met if the site characterization conclusions based on classification data matched the conclusions based on all intrusive results. Numerical estimates such as MEC density and MEC depth are considered consistent if they match within 25% of the estimates based on intrusive results. The project was deemed successful if only one of the classification-based RI/FS conclusions does not match the intrusive results-based conclusions.

4.0 SITE DESCRIPTION

The Motlow Range Complex MRS encompasses 3,646 acres and was the western artillery firing range for the former Camp Forrest. It is approximately 3 miles west of Tullahoma, TN.

The MRS has been divided into three general investigation areas for the RI/FS:

- Area 1 (Prior Removal Action Areas), where MEC may have been present but has now been removed
- Area 2 (Former Range Areas and Firing Points), where there is strong evidence of prior munitions use so MEC are potentially present
- Area 3 (Buffer Areas and Small Arms Ranges), where there is minimal or no evidence of MEC presence

For the RI, Area 2 has been subdivided into two parts based on prior use: Area 2a includes possible impact areas, and Area 2b includes possible firing points. The TEMTADS demonstration was performed primarily in Area 2a, where the highest density of MEC was expected. The investigation areas are shown on Figure 4-1. Areas 2a, 2b, and 3b all include several noncontiguous portions of the site.

4.1 SITE SELECTION

This site was selected as an RI/FS classification demonstration site. The site was selected for numerous reasons:

- An RI/FS project was planned for spring 2013, allowing a demonstration of the classification technology to be integrated with that project.
- Based on the results of previous removal actions at the MRS, MEC was expected at the site, and remedial alternatives that will be evaluated in the FS are expected to include subsurface removal.
- The entire site was expected to contain a sufficient number of anomalies (>5,000) to make classification a cost-effective alternative.
- There are a limited number of MEC types expected at the site, which will result in a higher percentage of non-TOI classifications.
- The smallest expected TOI was a 37-mm projectile, a munition that has been successfully classified at several ESTCP demonstration sites.
- The state regulatory agency was open to considering remedial alternatives involving classification.

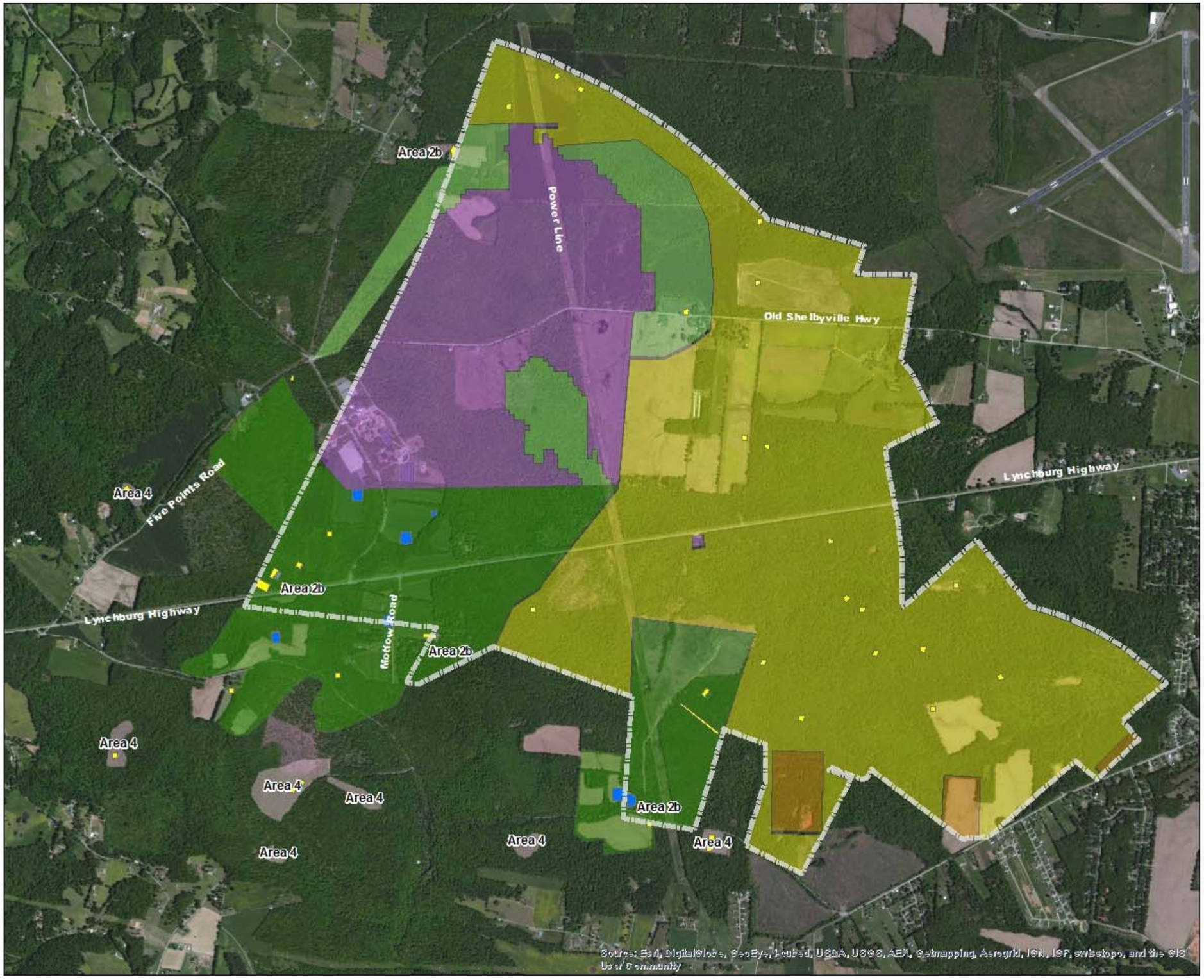


Figure 4-1

Investigation Areas and Grid Locations
Formerly Used Defense Site
Motlow Range
FUDS Project # G04TN019506

Tullahoma, TN

Legend

Range Complex MRS Boundary

RI and ESTCP Grid Data

- RI Only Grids
- RI and ESTCP Grids

Investigation Areas

- Area 1 Prior Removal Action Area (706 acres)
- Area 2a Direct Fire, Range Fan, & Wetland Area (305 acres)
- Area 2a 37mm & Mortar Impact Area (935 acres)
- Area 2b Possible Firing Points (4.2 acres)
- Area 3a Buffer Area (1,941 acres)
- Area 3b Small Arms Ranges (66 acres)
- Area 4 Additional Areas (57 acres)

N

Projection: Tennessee State Plane, NAD83, Feet

2,000 1,000 0 2,000 Feet

PARSONS	U.S. ARMY ENGINEERING & SUPPORT CENTER HUNTSVILLE, ALABAMA

DESIGNED BY: CM	Motlow Range		
DRAWN BY: CM			
CHECKED BY: CM	SCALE: As Shown	PROJECT NUMBER: 748565	
SUBMITTED BY: CM	DATE: March 2014	PAGE NUMBER:	
	FILE: S:\G\Shared\ESTCP RIFS Sites\Motlow\ESTCP Report\Maps		

4.2 SITE HISTORY

The Motlow Range was used for anti-tank, anti-aircraft (towed target), aircraft machine gun, and small arms training between 1941 and 1946. Additional details about the site history can be found in the archives search report supplement (U.S. Army Corps of Engineers [USACE], 2004). In December 1954, the USACE, South Atlantic Division conducted a preliminary inspection to determine the requirements for additional dedudding operations. This inspection revealed evidence of 60-mm and 81-mm mortar shells, as well as 30- and 50-caliber shells, hand grenades, and rifle grenades. Clearance activities were performed over 3,604 acres from 1955 to 1956, with subsequent periodic inspections from 1957 through 1969. Occasional recoveries of a variety of ordnance were reported during these inspections. Various removal actions were performed between 1995 and 2008, providing the most specific lists of the types of MEC recovered from the site. Based on these investigations, the munitions listed in subsection 4.4 have been used at the former Motlow Range.

4.3 SITE GEOLOGY

There are three soil associations in the former Motlow Range. The first and largest is the Dickson-Mountview-Armour association. It is composed of gently rolling and rolling, well-drained and moderately well-drained, silt loams on broad ridge caps, and nearly level, poorly drained silt loams in depressions and near the head of drainageways. The Dellrose- Mimosa-Rock Outcrop association consists of steep, cherty, well-drained upland soils with brown, cherty, silty clay loam subsoils greater than 6 feet to bedrock; steep, well-drained, cherty upland soils that have yellowish brown, firm, plastic subsoils 2 to 5 feet to bedrock; and areas of outcropping limestone. The third is the Bodine-Mountain-Ennis association. It consists of deep, well-drained, silty soils on steep hillsides leading to narrow cherty bottom soils along meandering drainageways.

4.4 MUNITIONS CONTAMINATION

The suspected munitions in this demonstration area include but are not limited to the following:

- 37-mm projectiles
- 105-mm projectiles
- 60-mm mortars
- 3-inch Stokes mortars,
- 81-mm mortars
- 155-mm projectiles
- 2.36-inch rockets

The vast majority of the MEC found at the Motlow Range Complex during the past removal actions are 37-mm projectiles. A former mortar range in the southern part of the site was expected to contain 60-mm, 81-mm, and 3-inch Stokes mortars. The technology demonstration was performed in high-density areas within the 37-mm projectile ranges. Portions of the mortar range area would have been selected for the demonstration, but they were deemed inaccessible to the TEMTADS sensor due to thick vegetation and wet ground conditions.

4.5 SITE CONFIGURATION

The TEMTADS was demonstrated on anomalies detected with the EM61 in high-density grids (6.25 acres). These grid locations were selected based on the anomaly density transects that were collected during Phase 1 of the field portions of the RI/FS. Eventually, flagging ribbon was tied to the wheat above the pin-flags to allow faster data collection.

More than 1,000 anomalies were contained within the high-density grids. Due to time lost to equipment repair and the limited window of TEMTADS availability, only 903 anomalies were collected. All of the targets where TEMTADS data were collected were intended to be intrusively investigated. However, only 794 of the anomalies were intrusively investigated because one landowner revoked right of entry after the TEMTADS data had been collected.

Figure 4-2: Data Acquisition with the TEMTADS Sensor

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The objective of this project was to demonstrate a method for the use of classification in the RI phase of the munitions response process. The three key components of this method were collection of high-quality geophysical data; analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and materials properties; and use of those parameters to construct a ranked anomaly list. In addition to these primary objectives, the data collected for this RI was reviewed as a simulated remedial investigation using the advanced classification data to select a limited set of targets for intrusive investigation that would provide the most useful data for site characterization.

5.2 SITE PREPARATION

The demonstration project was preceded by several activities performed by the RI team. The RI team collected EM61 transects to determine the anomaly density distribution at the site and selected grid locations based on those results. They surveyed the grid corners, removed vegetation from the grids and collected EM61 data in those grids. The RI team analyzed the EM61 data and selected anomalies that would later be investigated with the TEMTADS. Those anomalies were reacquired using RTK GPS equipment and were marked with plastic pin flags in the field. On the first day of reacquisition, the locations of the anomalies were refined using an EM61 sensor, but few were moved a significant distance. On subsequent days, the flags were placed at the coordinates of the anomaly based on the initial EM61 survey data. The in-field TEMTADS inversion was used to confirm that the sensor was close enough to the target to collect data that could be used to make a confident dig decision for the targets.

5.3 SYSTEM SPECIFICATION

Equipment used for this demonstration project included the EM61 electromagnetic metal detector, a real-time kinematic GPS, and the TEMTADS. The EM61 and RTK GPS equipment has been used on hundreds of previous military munitions response projects and will not be discussed in detail in this report. Specifications for the TEMTADS are included in Section 2 of this document.

5.4 BLIND SEEDING

Parsons QC personnel buried seed items across the demonstration site to demonstrate the effectiveness of the TEMTADS classification process. The location, orientation, and depths of the seed items were not provided to the data analyst. The data analyst was aware of the types of seed items used and built the classifier to identify those items in addition to the munitions expected at the site.

Primarily small pipe nipples (1-inch interior diameter, 4-inch length, both schedule 40 and 80) were used as seed items because they are similar to the main TOI expected at Motlow (37-mm projectiles). Some medium ISOs (2-inch diameter, 8-inch length schedule 40 pipe nipples) were also used in areas of the site where larger munitions such as 60-mm and 81-mm mortars were expected.

Seed items were buried at various depths, with the small items no more than 22 cm below ground surface (bgs) and the medium ISOs no more than 55 cm bgs to ensure that signal-to-noise ratios allow for EM61 detection. Seeds were placed in various orientations to ensure variability in tests upon detection and classification.

One hundred seed items were buried across the areas of investigation immediately after brush clearance and before the EM61 dynamic survey. The seeding team used RTK GPS equipment to measure the coordinates of each seed item and a ruler to measure the depth to the center of mass.

During seeding, the team excavated and backfilled each hole to reduce visual indications of seeding activities (e.g., disturbed soil or vegetation).

While 100 seed items were buried, only 54 of the seed items were located at anomalies where TEMTADS data were collected and intrusive investigation was permitted. Due to the high

density of anomalies in the demonstration areas and the limited time during which the team had access to the TEMTADS, some of the areas that were seeded for the demonstration were not visited with the TEMTADS. Some of the seeded items were not intrusively investigated because one landowner revoked the right of entry to that property after the TEMTADS data were collected.

5.5 CALIBRATION ACTIVITIES

For the TEMTADS family of sensors, a significant amount of data has been previously collected, both on test stands and under field conditions, during ESTCP demonstration projects and as part of a pilot study performed at the former Camp Beale. These data and the corresponding fit parameters provided a set of reference parameters including those of clear background (i.e., no anomaly present).

Daily calibration efforts consisted of collecting background (no anomaly) data sets periodically throughout the day at quiet spots. The data processor used these background data sets to remove the background response from data points collected over anomalies. The items emplaced in the IVS were measured twice daily to verify that the TEMTADS was functioning correctly. The IVS data were considered acceptable if the data were classified as their actual source objects with a confidence metric of 0.9 or higher (Section 3.4).

One of the seed items used for this project, the schedule 80 1-inch interior-diameter pipe nipple, was not in the standard TEMTADS library. Data collected at the site over one of those items was added to the reference library used for classification.

5.6 DATA COLLECTION

A team of two geophysicists and a UXO technician escort collected cued TEMTADS data over selected anomalies.

5.6.1 Scale

The demonstration was performed over approximately 6.5 acres of grids in high-anomaly-density areas within the MRS (Figure 4-1). The team collected TEMTADS data at 903 target locations within this area. Problems with the TEMTADS transmitter electronics and the limited time for which the instrument was available prevented the collection of all 1,000 anomalies that were initially planned. Of the 903 TEMTADS targets, 794 were intrusively investigated. One property owner's revocation of right of entry prevented intrusive investigation of the remaining 109 anomalies.

5.6.2 Instrument Verification Strip Data Collection

An instrument calibration check was conducted at an IVS strip containing four small ISOs (Table 5-1) at the beginning and the end of each field day to confirm that the equipment was functional, properly calibrated, and stable. The IVS data were sent to a remote analyst for evaluation.

Table 5-1: Instrument Verification Strip Items

ID	Seed type	Depth bgs (cm)	Orientation	Inclination
ISO-1	Small ISO	11.0	N	Horizontal
ISO-2	Small ISO	11.0	N	Horizontal
ISO-3	Small ISO	24.8	N	Horizontal
ISO-4	Small ISO	11.0	N	Horizontal

5.6.3 Background Acquisition

Background data collection points were collected before and after IVS data collection and at intervals of 2 hours or less during high-density-area data acquisition. Each target point was associated with a background point based on time of data collection.

5.6.4 Sample Density

The EMI data spacing for the TEMTADS is fixed at 40 cm in both directions by the array design.

5.6.5 TEMTADS System Parameters

The TEMTADS single-point or cued-collection mode was used for all data collection at Motlow. After the TEMTADS was positioned correctly above the flag placed by the reacquisition team, the operator collected a data point using the settings indicated in Table 5-2.

Table 5-2: TEMTADS Acquisition Parameters Used at Motlow

Mode	Acq. Mode	Hold-Off Time (us)	Block T	Repeats	Gate Width	Stk Const	Gate Holdoff (ms)	No. Gates	Sample Rate (S/s)
Static	2	25	0.9	9	0.05	18	0.005	121	N/A

5.6.6 Data Handling

Data were recorded in binary format as files on the hard disk of the data acquisition computer. These data were offloaded to other media at least once, and sometimes more frequently, per day. The computers' hard disks had enough capacity to store all the data from the entire site, so these data were not erased until they had been thoroughly reviewed and archived. The data file names acquired each day were cataloged (usually on a spreadsheet) and integrated with any notes or comments in the operator's field book. All data ended up on the hard drives of one or more laptop computers used to post-process data. Data were also archived to a data server in the Parsons office.

Raw TEMTADS files were converted to .csv files using the TEM Datalogger program used to collect the data. TEMTADS .csv files were not translated to Universal Transverse Mercator coordinates and were not background corrected. Background correction was accomplished using the Level Advanced Sensor Data tool in UX-Analyze, and translation was performed in the project's Microsoft Access database after most classification had already been performed.

5.6.7 Data Quality Checks

An instrument calibration check was conducted at the IVS strip at the beginning and the end of each field day to verify that the equipment was functional, properly calibrated, and stable. The data collected over the IVS test items were background corrected, inverted, and compared with the TEMTADS library to determine which item most closely matched the data and how closely it matched.

Quality checks of all static data points were performed after initial inversion was completed using the UX-Analyze module in Oasis montaj. Inverted target locations were compared to data collection locations to determine if offsets between the two were greater than 40 cm. All background points collected at the site each day were compared with one another, and those that appeared to include targets were not used for background corrections.

5.6.8 Intrusive Validation

Intrusive operations on the demonstration project anomalies at the former Motlow Range began on May 14, 2013, and ended on May 31, 2013. Operations began with the site-specific training, which included preparing the staging area for intrusive activities and performing equipment checks. The staging area consisted of a 20-foot-long metallic storage unit and a mobile office on the Motlow State Community College grounds. Daily equipment checks included confirming GPS accuracy over known monuments, performing static tests with the EM61, and verifying that handheld analog instruments were functioning correctly.

Personnel on site to conduct the intrusive operation included Parsons and USA Environmental, the UXO explosives subcontractor. The field team consisted of six Parsons personnel and two USA Environmental personnel. Parsons' site safety and health manager and the Parsons' site manager conducted daily site safety briefings, as appropriate.

The team intrusively investigated 794 of the TEMTADS anomalies. The demonstration plan included intrusive investigation of all anomalies where the TEMTADS was used. However, 109 anomalies in grid HD09 could not be investigated after one property owner revoked the right of entry that had been previously provided.

The intrusive investigation process included the following steps:

1. Search around the flagged anomaly location using the EM61 and analog detector to locate peak response location.
2. Uncover the metallic objects at that location.
3. Repeat steps 1 and 2 until the EM61 response in the area indicates that no metallic items remain at the target location.
4. Record the position of each uncovered metallic object using an RTK GPS with cm-level accuracy.
5. Measure the length and depth to the center of mass of each uncovered metallic object using a metric tape measure.
6. Record the measurements and description of the recovered items on a paper dig sheet with the target identification (ID).
7. Place all recovered metallic objects on a white board with the site name, grid ID, date, target ID, length(s), depth(s), and dig type(s).
8. Photograph the white board with the metallic objects.
9. Backfill the target location.

Excavation data collected by the intrusive team was scanned and uploaded to the Parsons Denver server, where it was entered into a database and reviewed daily. The daily information required the target ID to be connected with intrusive documentation, photo, and GPS coordinates. Assessment of each target item required the coordinates to match the original location and the picture to match the documented findings.

All metallic items recovered at the investigated anomalies, excluding the seed items, were placed in a 55-gallon drum for storage. Two 55-gallon drums were filled with the munitions debris (MD) and other debris, and seeds, weighing a total of 495 pounds.

The intrusive team recovered six MEC items at the 794 investigated anomalies. As expected based on past work at the site, most of the MEC items were 37-mm projectiles (three anti-personnel and one high-explosive). One of the MEC items was a 155-mm shrapnel projectile and one was a 37-mm projectile fuze. All MEC items except for the 37-mm projectile fuze were considered TOI for the demonstration. The 37-mm projectile fuze was not considered TOI because it is too small to produce a sufficient response that can be meaningfully inverted. Three hundred sixty-one pieces of munitions debris and 686 pieces of non-munitions-related debris, mostly farming tools, were recovered during the investigation. The team successfully determined the size of munition with which some of the munitions debris was related. These items included small arms, 37-mm projectiles, 60-mm mortars, 75-mm projectiles, 81-mm mortars, and 155-mm projectiles.

Figure 5-1: Intrusive Operation Photos

6.0 DATA ANALYSIS AND PRODUCTS

The TEMTADS was used to collect static data over 903 targets identified in the open areas at the former Motlow Range using EM61 data. The processing and analysis steps that were used to generate a dig/no dig decision for each target are described below.

6.1 TEMTADS PREPROCESSING

The TEMTADS acquisition software allows for the naming of files at the time of collection, so all TEMTADS points were identified using the EM61 target ID on the target list. Additional TEMTADS points collected over targets were named by adding 10,000 to the ID of the last points collected at that target. Conversion of the raw data files to text readable .csv files was accomplished using the TEM Datalogger program used to collect the data. These were imported into Oasis montaj for all further processing. Background correction for each point was accomplished using the Level Advanced Sensor Data tool in UX-Analyze. The background points were typically used to correct data points collected 1 hour before to 1 hour after the collection of the background point.

6.2 PARAMETER ESTIMATION

All data points were inverted using UX-Analyze to determine modeled parameters for each target. These parameters included the location, size, and orientation of the source object; the polarizability of each axis of the object; and information regarding the quality of the data and the relative match between the inverted data and the expected model.

All target inversion was initially performed using the UX-Analyze batch processing mode with both the multiple object solver and the single object solver. Single object and multiple object results were compared to determine which method returned a result more indicative of TOI. Although the multiple object result may have approximated the expected model to a higher degree, the result more indicative of potential TOI was used for target ranking to be conservative unless the source that appeared to be TOI was outside of the assumed effective radius of the sensor (See Section 7.4).

6.3 CLASSIFIER AND TRAINING

The polarizability curves developed for each target were compared to a library of known polarizability curves compiled using previous test stand data, known TOI from other sites, and test data collected at Motlow. The items in the Motlow comparison library were 37-mm, 75-mm, 105-mm, 155-mm, and 3-inch projectiles; 50- and 81-mm mortars; and small and medium ISOs. An initial comparison between the measured targets and the library data was performed using a weighted confidence metric for the three primary polarizabilities (size [primary axis polarizability]: 1, shape 1 [secondary axis polarizability]: 0.5, shape 2 [tertiary axis polarizability]: 0.5). During this comparison, the seven results from the multiple object solver were compared to the library, and the one with the highest confidence metric was selected for use with that target. If the result selected was not the one already in the target database, the database result was replaced. All further confidence metrics were generated using the multiple object result selected during the weighted metric comparison. In addition to the weighted confidence metric generated during the initial comparison of the results to the library, three more

metrics were generated for each target, a 3-curve metric, a 2-curve metric, and a 1-curve metric. Table 6-1 shows the weighting given to each polarizability curve in the various library comparisons

Table 6-1: Comparison Weights for Confidence Metric Calculation

Confidence Metric	Size (β1; Primary Curve) Weight	Shape 1 (β2; Secondary Curve) Weight	Shape 2 (β3; Tertiary Curve) Weight
Weighted Metric	1.0	0.5	0.5
3-Curve Metric	1.0	1.0	1.0
2-Curve Metric	1.0	1.0	0.0
1-Curve Metric	1.0	0.0	0.0

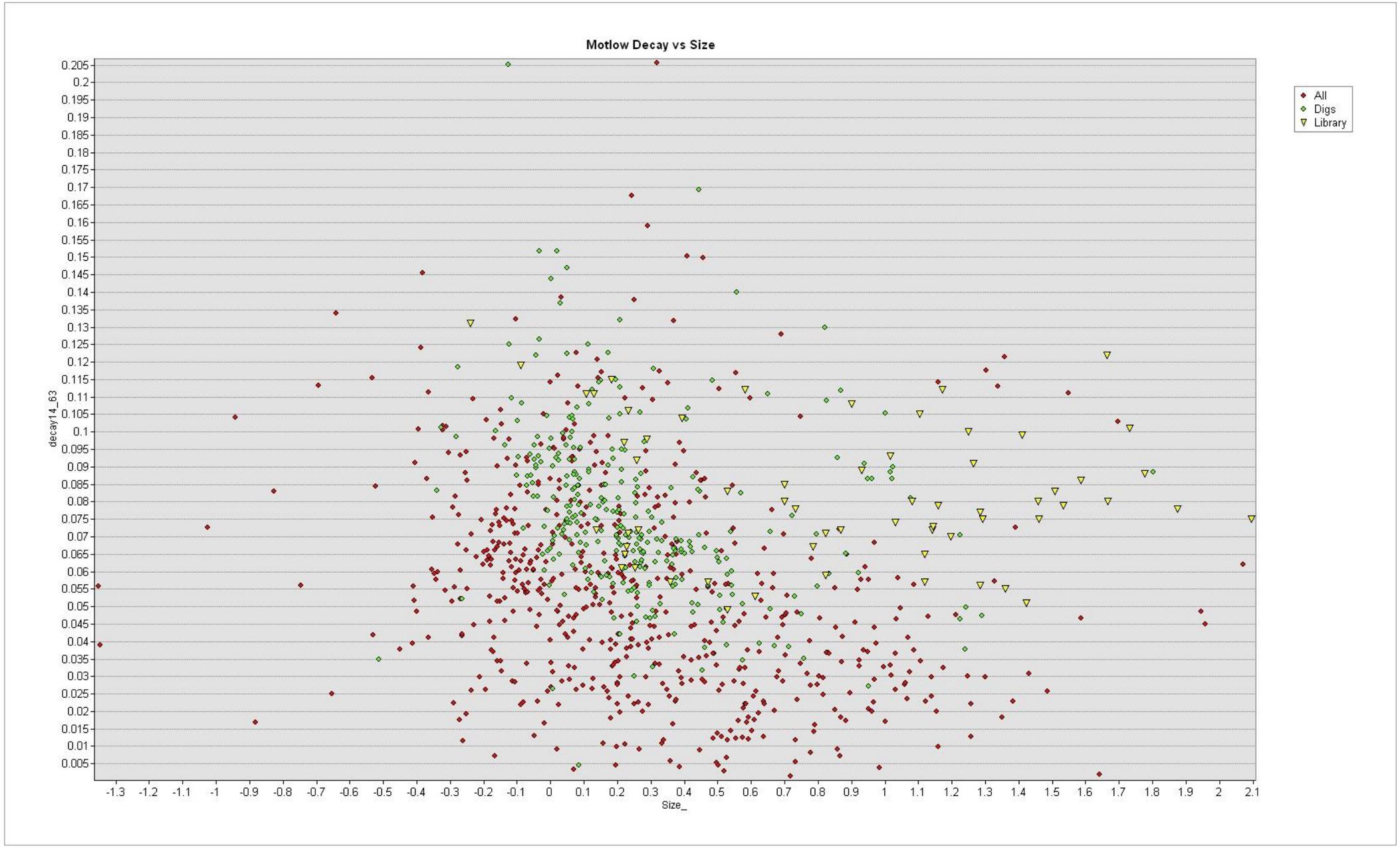
As a first step, each target was examined by looking at a figure showing the two closest matches for the weighted, two-curve, and one-curve comparisons to the library. Results were generally grouped into one of five groups:

1) All three polarizability curves (β1, β2, β3) were usable
2) Only two of the curves (β1, β2) were usable
3) Only β1 was usable
4) No usable curves, but it was determined unlikely that there was a source large enough to be TOI in the acquisition location, or the target in question was picked on the edge of a dynamic anomaly and there was another point collected on that anomaly that was of sufficient quality for use in classification
5) Can't analyze (no usable curves, and it was considered likely that the curves were unusable despite the existence of a source potentially large enough to be a TOI)

The difference between targets deemed likely to have a source potentially related to the target and those with unusable curves due to a small or nonexistent source was typically determined based on the modeled location of the source relative to the collection point and the appearance of the anomaly in the dynamic dataset. Targets on the edge of anomalies that had source locations modeled toward another peak on that anomaly were generally considered useable data given the likelihood that the source was underneath a different target Similarly, poor TEMTADS data collected over small anomalies that looked like they were potentially due to geophysical noise in the dynamic dataset rather than an actual large source were generally considered useable data.

After evaluating all the targets to determine how many of the polarizability curves were usable, the multi-object inversion results were plotted on a size-decay plot (Figure 6-1). This plot was visually inspected looking for clusters of results that could represent munitions that were not included in the library and would provide useful training data for potential modifications to the classifier. However, the size-decay plot for the data collected at Motlow did not have the ideal clustered groups of results separated from the numerous small metal object results with low decays and small size. This is likely due to the lack of large munitions items used at the site and the variety of small objects (small ISOs, 37-mm projectiles, 37-mm projectile fragments, and pieces of farm equipment) that made up most of the target results. Because no such clusters were identified, the data analyst declined to request any training data to refine the classification analysis.

Figure 6-1: TEMTADS Size-Decay Plot



6.3.1 Target Classification

Two dig lists (lists 1 and 2) were submitted for the Motlow project using two differing classifiers. Classification decisions for each were primarily made using the four confidence metrics generated for each target during the comparison to the library data, with differing confidence metric thresholds used to separate TOI from non-TOI on the two lists. Dig List 1 used higher thresholds than Dig List 2 and was based on TEMTADS metrics that would have been successful on Parsons TEMTADS project at Camp Beale in California had they been used for that project (thresholds identified following comparison of Beale dig list to ground truth). Dig List 2 used lower thresholds that have proven successful on numerous previous MetalMapper projects and that were actually used for Camp Beale TEMTADS data. The decision logic for each dig list is shown in Table 6-2.

Table 6-2: Categories for Motlow Cued Targets

Category	Dig	Weighted or Three-Curve Confidence Metric	Two-Curve Confidence Metric	One-Curve Confidence Metric	Comment
Dig List 1					
0	Yes	NA	NA	NA	Can't analyze; data deemed unusable for classification
1	Yes	≥ 0.75	≥ 0.75	≥ 0.85	All three are true; others close to passing added at analyst's discretion
2	Yes	NA	≥ 0.75	≥ 0.85	One non-β1 curve considered poor; other two true
3	Yes	NA	NA	≥ 0.85	Two non-β1 curves judged poor; β1 curve looks like TOI
4	Yes	NA	NA	NA	Added based on large geophysical size
5	No	< 0.75	< 0.75	< 0.85	Any one of three is true
Dig List 2					
0	Yes	NA	NA	NA	Can't analyze; data deemed unusable for classification
1	Yes	≥ 0.75	≥ 0.75	≥ 0.85	All three are true; others close to passing added at analyst's discretion
2	Yes	NA	≥ 0.75	≥ 0.85	One non-β1 curve considered poor; other two true
3	Yes	NA	NA	≥ 0.85	Two non-β1 curves judged poor; β1 curve looks like TOI
4	Yes	≥ 0.65	≥ 0.70	≥ 0.80	All three are true; also added based on large geophysical size
5	No	< 0.65	< 0.70	< 0.80	Any one of three is true

Each dig list was ranked according to ascending category and descending weighted confidence metric.

6.3.2 Site Characterization

In addition to goal of demonstrating that advanced classification could be successfully applied at Motlow, this project also includes an evaluation of using classification data to characterize the MEC contamination at a site with a reduced intrusive investigation effort. For that part of the project, a geophysicist reviewed the classification results and performed additional analysis of the TEMTADS data to select a limited list of specific anomalies that would provide the most useful information for characterizing the MEC contamination at Motlow. These additional analyses included:

- Comparing the entire set of TEMTADS polarizability curves with libraries of MD related to specific types of MEC (e.g., 37-mm projectiles, 105-mm projectiles, rifle grenades) from other demonstration projects (i.e., Camp Beale and Spencer Artillery Range).
- Comparing the entire set of TEMTADS polarizability curves from Motlow with itself, looking for clusters of anomalies with similar characteristics.
- Assigning feature characteristics for each anomaly to different groups for size (small, medium, large), shape (flat, axially symmetric, spherical), decay (fast, medium, slow), and depth (deep, medium, shallow).
- Creating maps of the different feature characteristic groups, MEC types, and clusters identified during the analysis described above.

Based on these efforts, 74 targets that met one of the following criteria were selected as most representative of the MEC at Motlow:

- Targets that matched the library of TOI with a weighted metric of 0.9 or higher.
- Targets that matched the MD related to specific MEC from other sites with a weighted metric of 0.875 or higher.
- Targets that represented clusters of three or more inversion results that matched each other with at least a 0.95 metric. At least one target from each cluster was selected.
- Targets classified as “large” with a weighted metric of 0.8 or larger.
- Targets classified as “deep” (i.e., depth >30 cm) with a weighted metric of 0.8 or larger.
- Targets classified as large in grid HD09. Many targets classified as “large” were in HD09 but did not match library items very well; the six targets with the best fit metric were selected for intrusive investigation to characterize the nature of the items in this high-anomaly-density area.

In addition, any anomalies associated with blind seed items or which were not intrusively investigated were not included on the list of targets that would be used to characterize the site. The intrusive results from these anomalies were used to answer these four questions:

1) What type of MEC may be present at the site?
2) What is the MEC density (MEC per acre) at the site?
3) What is the horizontal extent of MEC contamination at the site?
4) What is the maximum depth of MEC contamination at the site?

6.3.2.1 Types of Munitions and Explosives of Concern

The targets selected for intrusive investigation included two MEC items: one 37-mm HE projectile and one 155-mm shrapnel projectile. Two additional TOI, 37-mm armor-piercing projectiles, were found that are similar in size and shape to 37-mm HE projectiles but pose no explosive hazard. Fragments of the same size munitions were also found at other target locations that were selected for intrusive investigation.

6.3.2.2 Munitions and Explosives of Concern Density

Two MEC were found in the 6.5 acres of grids covered by the TEMTADS. The MEC density was calculated by dividing the number of MEC items found (two) by the intrusively investigated portion of the high-anomaly-density area in which MEC may be present (3.25 acres). The estimated MEC density is 0.46 MEC per acre.

6.3.2.3 Extent of Munitions and Explosives of Concern Contamination

The RI estimated the horizontal extent of MEC contamination based on the results of the EM61 transects and the intrusive investigation within the high-density areas. Based on the MEC and MD found in high-density Areas 4, 5, 6, and 9, the classification characterization approach concluded that MEC may be present in those areas but not within firing point 6 or high-density Area 3, where no munitions related materials were recovered. The four potentially contaminated grids are within one high-anomaly-density area, while the uncontaminated grids are in other high-density areas. The extent of MEC contamination is therefore the extent of the high-anomaly-density area where the MEC were found.

6.3.2.4 Depth of Munitions and Explosives of Concern Contamination

The MEC were found at depths of 51 cm (155-mm projectile) and 8.5 cm (37-mm projectile, HE). Three armor piercing 37-mm projectiles were determined to be MD items, but they were considered TOI for this technology demonstration project. The depths of these items (2, 4, and 11 cm) were also considered when characterizing the vertical extent of MEC. Based on these results, the vertical extent of all types of MEC is 51 cm, while the vertical extent of 37-mm projectile-sized MEC is 11 cm.

6.3.2.5 Limits of Site Characterization

This technology demonstration was limited by the quantity of TEMTADS data that could be collected in the time that the sensor was available and by the parts of the site that could be accessed with the sensor. Thus, the TEMTADS was only used in the southern and western parts of the site. To assess the results of using classification data to characterize the site, the only conclusions that will be evaluated are those from the part of the site where the TEMTADS was used.

6.4 DATA PRODUCTS

6.4.1 Pre-Excavation Dig Lists

The targets on the dig list were ranked according to priority and confidence metric. The lists were sorted first by priority ascending, then by confidence metric descending. Priority 1, 4, and 5 targets were sorted using the weighted confidence metric, priority 2 targets were sorted using the two-curve metric, and priority 3 targets were sorted using the one-curve metric. Table 6-3

contains the applicable classification statistics for each dig list submitted prior to the intrusive investigation.

Table 6-3: Ranked Dig List Summary Statistics

Statistic	List 1 (number / %)	List 2 (number / %)
Points Collected	903 / 100%	903 / 100%
Targets labeled as digs	312 / 35%	417 / 46%
Can't Analyze	13 / 1%	13 / 1%
Category 1	280 / 31%	280 / 31%
Category 2	6 / < 1%	6 /< 1%
Category 3	10 / < 1%	10 / < 1%
Category 4	3 /<1%	108 / 12%
Targets labeled as clutter Category 5	591 / 65%	486 / 54%

7.0 PERFORMANCE ASSESSMENT

7.1 GLOBAL POSITIONING SYSTEM/ACCURACY

The performance objective for the project was for all locations measured by the GPS to be within 10 cm of the expected locations for each test. All GPS tests met this performance objective.

7.2 EM61 STATIC TEST REPEATABILITY

The performance objective was for all measured responses to be within +/- 10% of the expected response. All EM61 static tests met this performance objective. The afternoon test was not collected for May 7, 2013, due to weather. The morning tests on May 7, 2013, and the subsequent days were acceptable; the missing tests were not considered a concern.

7.3 CORRECTLY LOCATE TEMTADS FLAG POSITIONS

The first 81 flags were located according to the project performance objectives detailed in Section 3.3, with flags resurveyed using the RTK GPS if they were farther than 30 cm from the picked location, and additional points were added as targets for flags farther than 73 cm from the picked location. This was only done for the first 81 TEMTADS anomalies; due to limited time with the TEMTADS unit, relocating of the flags based on the peaks EM61 response was omitted. Consequently, the remaining targets were placed on the picked EM61 target locations using a GPS. To ensure that the TEMTADS was placed over an item, the real-time inversion function was used to better pinpoint the location of the item. If the inversion resulted in the item being located more that 40 cm away, the point was recollected over the location indicated by the inversion results.

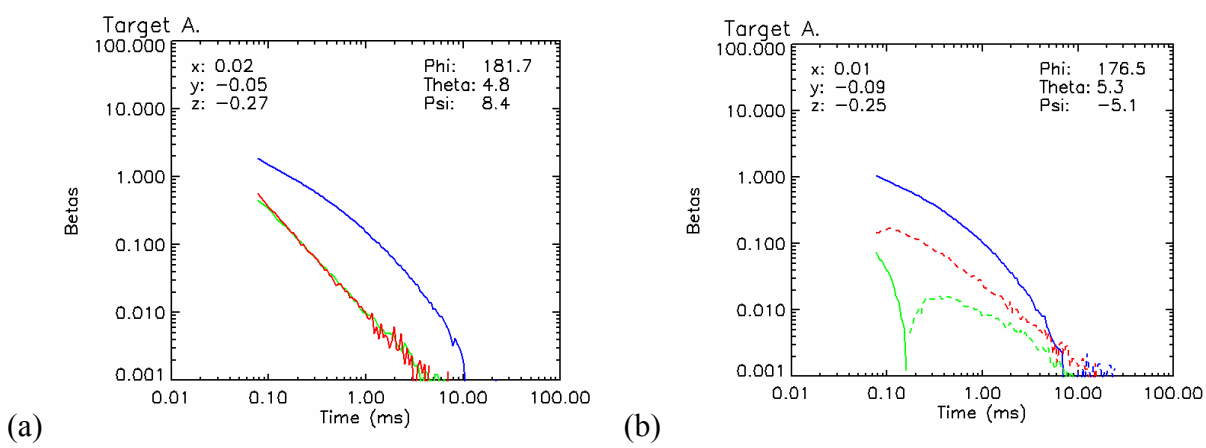
7.4 CORRECTLY IDENTIFY SEED ITEMS IN THE INSTRUMENT VERIFICATION STRIP

Five seed items were identified with a confidence metric of less than 0.7 in the TEMTADS IVS data. Out of 65 items surveyed, this represents 8% of the total IVS tests, which fails both the desired and success criteria for the project. Table 7-1 lists the IVS points that did not meet the requirement of having confidence metrics greater than 0.7. The secondary polarizability curves for these points did not match the secondary curves in the TEMTADS library, but the primary curves were good matches. Two examples of IVS polarizability curves, one good and one poor, are displayed in Figure 7-1.

Table 7-1: Instrument Verification Strip Data Point with Low Weighted Metrics

Dataset ID	Point ID	Description	Best Weighted Metric	Best Weighted Match	Comment
050313pm	3	Small ISO, horizontal	no match	Small ISO	Best Curve was Curve1 (0.9388) Beta Noise Value of 1.068
050313pm	4	Small ISO, horizontal	0.695	Small ISO	Best Curve was Crv_1 (0.9703) Beta Noise Value of 0.034
050713pm	3	Small ISO, horizontal	no match	Small ISO	Best Curve was Crv_1 (0.9569) Beta Noise Value of 1.70
050713pm	4	Small ISO, horizontal	0.563	Small ISO	Best Curve was Crv_1 (0.9678) Beta Noise Value of 0.038
050913pm	3	Small ISO, horizontal	0.457	Small ISO	Best Curve was Crv_1 (0.9755) Beta Noise Value of 0.21

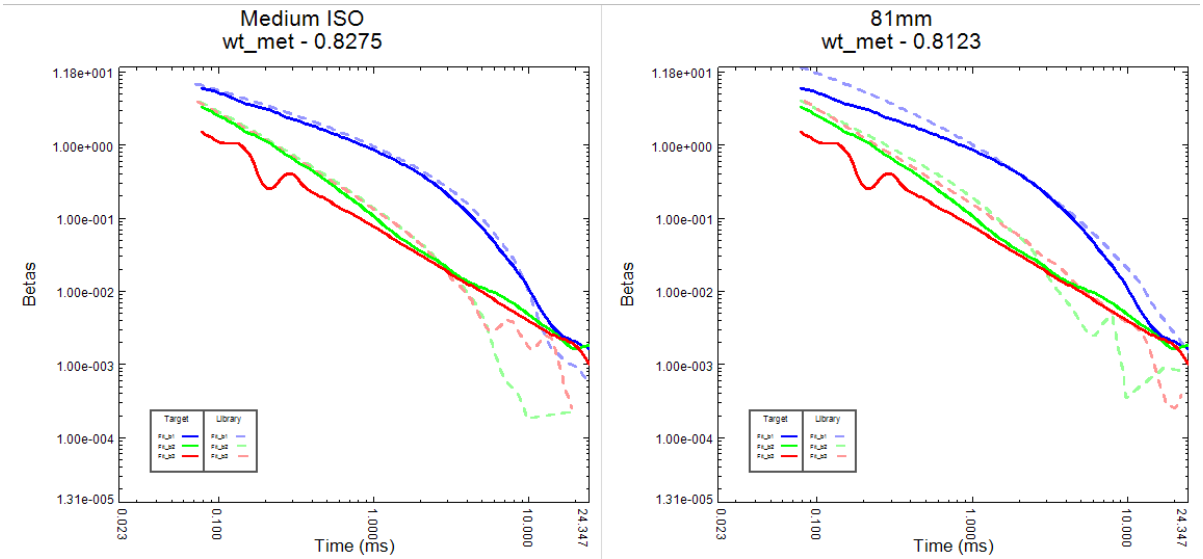
Figure 7-1: Polarizability Curves Derived from Data Collected over Instrument Verification Strip Item 3 in the Morning (a) and Afternoon (b) of May 7, 2013



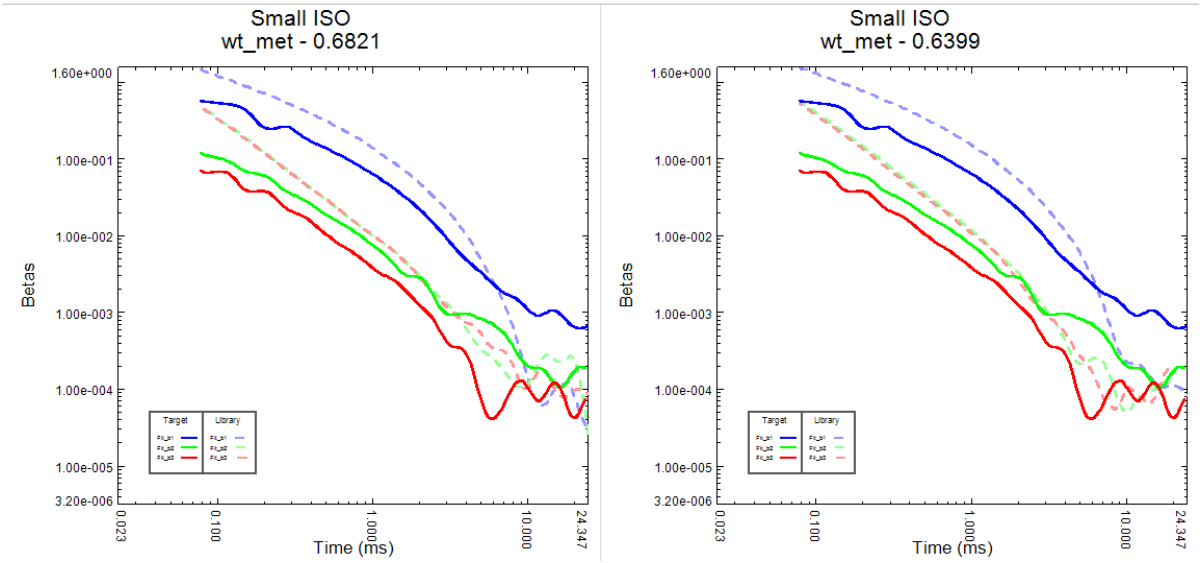
While the failures were concerning, the period over which the TEMTADS was available for use on the project was extremely limited, and Parsons was never sure whether the instrument was entirely functional. NRL personnel had to fly to the site at the beginning of the project to repair a transmitter that broke during shipping, preventing any useable data from being collected. Following the repair, the data collected still appeared somewhat questionable, given peaks and troughs repeatedly seen early in the polarizability curves for number of targets (Figures 7-2a and 7-2b). Despite the odd peaks and troughs, the data seemed usable given most of the IVS data and the fact that even these failures would have been classified as digs had they been field targets based on noise evident in the data and very high curve 1 confidence metrics. Given the short amount of time with access to the instrument before it had to be returned to NRL for another project, the decision was made to continue with data collection rather than spending the limited time troubleshooting an equipment problem that no one on site was qualified to repair.

Figures 7-2a and b: Examples of Peaks/Troughs seen in Data

A. Target 00292r



B. Target 00328



7.5 CORRECTLY POSITION SENSOR RELATIVE TO THE SOURCE

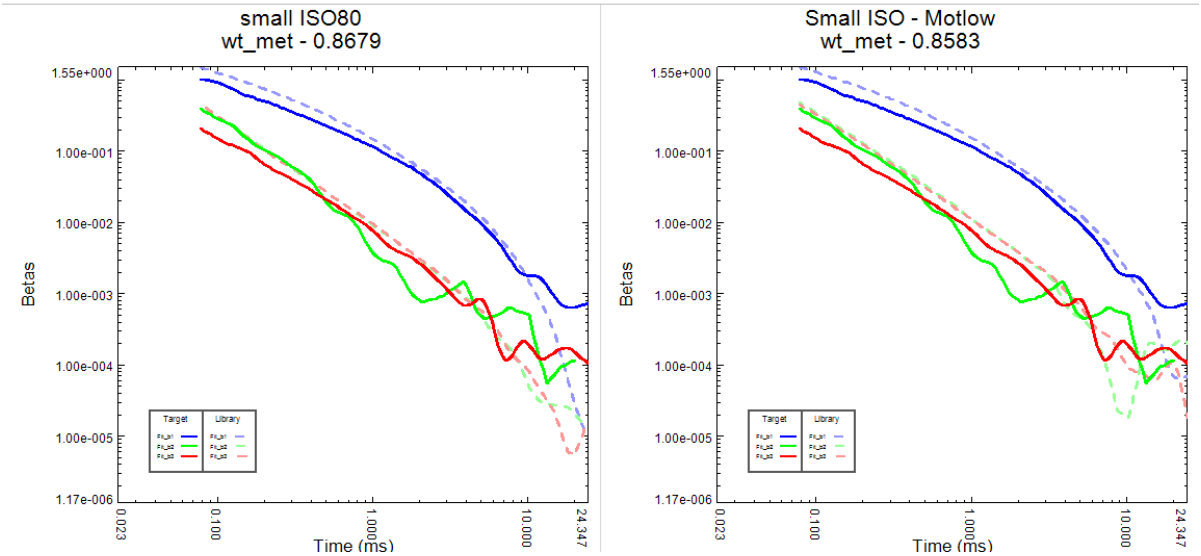
Two hundred fifty-two TEMTADS points were identified as targets that should be re-shot due to fit locations in the original data farther than 40 cm from the collection point. The high percentage of recollects (22%) can be attributed to the fact that only the first 81 flags were located on the peak EM61 response, while the remaining flags were placed over the picked EM61 points. The remaining flags had to rely on the real-time inversion function to accurately pinpoint the anomaly location. As a result, more anomaly locations had to be recollected because they were not placed over the peak EM61 response. However, 250 of the recollected points were collected efficiently because the team used the in-field inversion to identify necessary recollects and did not have to return to the point.

The remaining targets were collected as specified in Section 3.5. Forty-two final classification results had collected to fit offsets greater than 40 cm; however, this was a factor of the process used to select the version of each target that would represent each picked target location. Because only one result was necessary for each picked target, the analyst often had to choose between multiple results at each target location (primary object and secondary objects from the multiple object solver inversion; single target inversion) to identify the one result that would be used for the EM61 target in question. The result selected was at the discretion of the analyst. Generally, sources modeling outside of the sensor were considered poor representations of what was actually in the ground and were ignored in favor of sources closer to the center of the instrument with the assumption that the instrument was placed in the correct location for data collection. Exceptions were made for targets the analyst thought might actually be representative of TOI based on confidence metrics and the appearance of the curves. Curves that passed the confidence metric thresholds and actually appeared to curve, as opposed to appearing straight, were classified as digs. Straight curves were considered potential models of background or inaccurate models of nearby metal. Most of the high-offset targets are those for which a source modeled farther than 40 cm from the collection point were those that the analyst decided should be kept in favor of a result closer to the center of the sensor. A smaller subset of these instances is re-shot targets for which the re-shot was also greater than 40 cm from any modeled source.

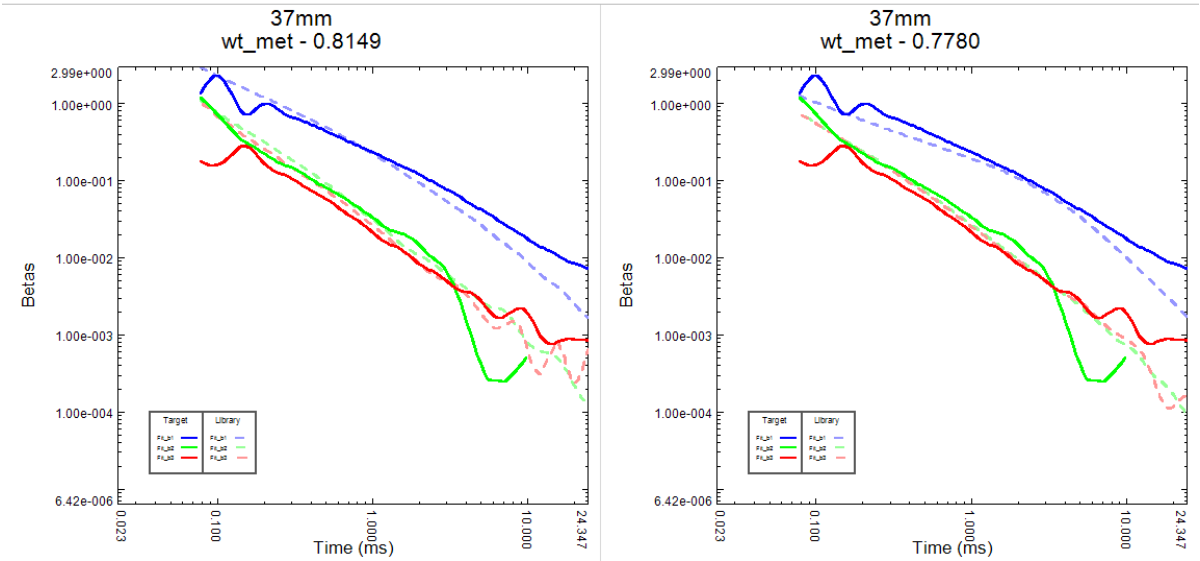
Figures 7-3a and b show on example of a target that was kept based on the above rationale and one that was ignored in favor of a result under the sensor.

Figures 7-3a and b: Examples of Curves Outside of the Sensor Radius

a. Classified as Potential TOI



b. Ignored due to Offset



7.6 MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

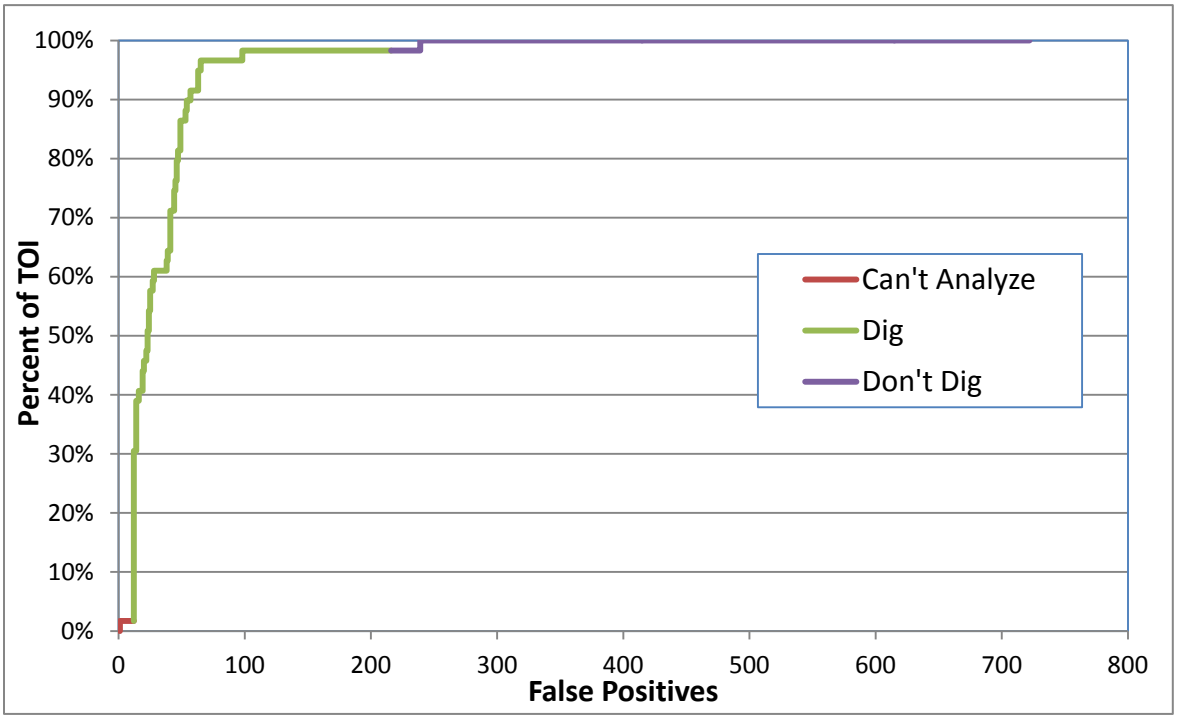
The ground truth data from intrusive investigations performed at Motlow were compared against two prioritized dig lists: an aggressive list (List 1) and a conservative list (List 2).

For List 1, 312 of the 903 targets (35%) were marked as "dig," including 58 out of 59 TOI (98.3%). The more conservative classifier used for List 2 marked 417 of the 903 targets (46%) "dig" and included 100% of the TOI on the "dig" list. Both approaches met the success criterion (>98% of TOI correctly classified) with the more conservative classifier meeting the objective of correctly identifying 100% of the TOI.

The results of the dig list comparisons to the ground truth lists were judged according to performance objectives identified for the project in the Motlow demonstration (Parsons, 2013). Table 3-1 contains the performance objectives and identifies the criteria by which they were judged. Results for the ground truth were compared to the correct classification of TOI, the correct classification of non-TOI, and the minimization of Can't Analyze performance objectives. Because there was only one set of Can't Analyze anomalies and the location of recovered items was identical between ground truth sets, there was only one result for the objectives regarding the number of Can't Analyze anomalies and the offsets between recovered items and identified locations. The results of the submitted dig lists with respect to each project objective and each set of ground truth data, if applicable, are detailed below.

Figure 7-4 shows the receiver operating characteristic curves for List 1. As indicated in the figure, 58 of the 59 TOI (98.3%) at the site were correctly identified as targets that should be dug. The one item missed, target MTL-495, was a small ISO. The performance objective success criterion was the correct classification of all TOI, so the misidentification of MTL-495 is a failure of the objectives.

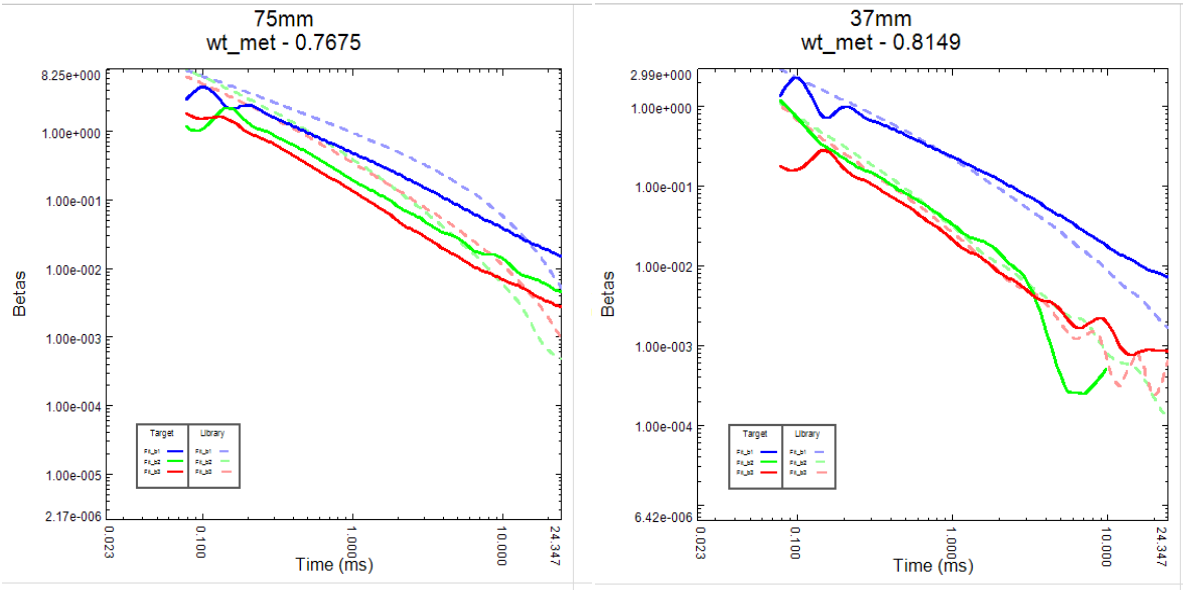
Figure 7-3: Receiver Operating Characteristic Curve for List 1



MTL-495 was a small ISO buried at 22.86 cm bgs. The EM61 detection survey produced a response of approximately 15 millivolts (sum of channels 1, 2, and 3). The ISO was buried at the maximum depth at which classification could be expected to be consistently effective. The inversion result used to make the dig/no-dig decision was the single object inversion, which modeled an object offset 29 cm from the sensor position. The multi-object inversion produced three results: two small objects near the center of the sensor and one larger object 0.43 meters from the center of the coil. The larger object matched a 37-mm projectile well enough to have been included as a Category 1 dig, but the single object result was used because it was assumed to be more representative of the source due to its proximity to the sensor and because the analyst felt that the larger object under the sensor, which was approximately the size of a 75mm projectile, was the intended target. There were 26 total cases of targets with a result passing all of the confidence metric thresholds that were classified as non-TOI based on an offset between the collection location and the modeled result of over 40 cm; this was the only one with a TOI result. The EM61 pick, which should have been used as the TEMTADS collection location and initial reacquisition location for the intrusive investigation, was 32 cm from the seeded location. Given that the next closest target was more than 3 m away, it is unclear why nothing was found or what, exactly, the TEMTADS was positioned over during collection. Further discussion of the missed TOI is included in the lessons learned (Section 9).

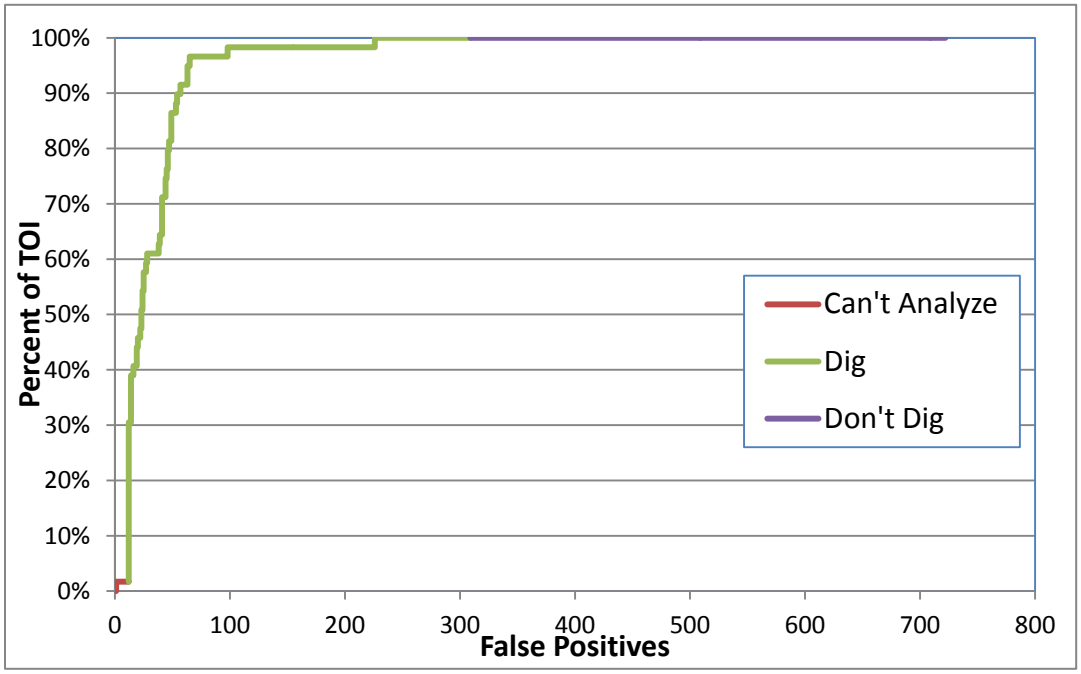
Figure 7-5: Inversion and Library Fit Results for Target 495

a. Single Object Method **b. Multi-Object Method**



The receiver operating characteristic curve for List 2 is displayed in Figure 7-5. As indicated in the figure, all 59 TOI at the site were correctly identified as targets that should be dug. The TOI that was misclassified in List 1, target MTL-495, was included as a dig on List 2 because Category 4 was expanded to include anomalies with lower fit metrics than were included for List 1. List 2 met the performance objective success criterion of correctly classifying all TOI.

Figure 7-5: Receiver Operating Characteristic Curve for List 2



7.7 MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

List 1, the aggressive classifier, identified 504 targets (70% of 721 non-TOI targets) as "no-dig," not meeting the performance objective of correctly classifying more than 75% of the non-TOI items while retaining at least 98% of the TOI on the "dig" list, but meeting the success criterion of removing at least 60% of the non-TOI from consideration for intrusive investigation. By correctly classifying 412 of the 721 non-TOI (57%), List 2, the conservative approach, did not meet either the performance objective or the success criterion.

7.8 CORRECTLY IDENTIFY TYPE OF TARGETS OF INTEREST

Fifty of the 59 TOI items (85%) were placed in the correct group, meeting the success criterion (>75%) but not the performance objective (>95%).

7.9 CORRECTLY IDENTIFY TYPE OF NON-TARGETS OF INTEREST

Approximately 79% of the non-TOI were classified in the correct group (small or large and cylindrical or plate-like). This level of accuracy did not meet the performance objective (>95%) for the project but did meet the success criterion (>50%).

7.10 MINIMIZE NUMBER OF CAN'T ANALYZE TARGETS

Only 13 out of 903 analyzed anomalies (1.4%) were categorized as Can't Analyze, meeting the performance objective of estimating reliable parameters for greater than 95% of the targets on the prioritized dig list.

7.11 CORRECT ESTIMATION OF TARGET PARAMETERS

The target parameters estimated in this case were the X, Y, and relative Z (depth) coordinates of the targets. Because the goal with this objective is to direct the dig teams to the correct locations for TOI, the comparison of estimated coordinates to actual coordinates was performed only for TOI and for those targets marked as digs in the ranked dig list.

For all targets listed as "dig," the standard deviation of the offset between recovered locations and modeled locations was 19 cm, meeting the project objective of <20 cm. The vertical offset standard deviation was 9 cm, also meeting the project objective of <10 cm. For anomalies with multiple recovered items, the coordinates for the item closest to the modeled location was used to calculate the horizontal and vertical offsets for that anomaly.

7.12 SITE CHARACTERIZATION

The site characterization conclusions based on the geophysical data and a limited quantity of intrusive data (74 targets) were compared with the overall RI results that were based on all data collected at the site. The advanced classification site characterization approach was evaluated based on the agreement with the RI in the following four areas.

7.12.1 Type of Munitions and Explosives of Concern

The classification site characterization concluded that 37-mm and 155-mm projectiles may be present at the site. This conclusion was consistent with the revised conceptual site model in the Motlow RI report that listed 37-mm and 155-mm projectiles as the known or expected general munitions types.

7.12.2 Munitions and Explosives of Concern Density

The MEC density was calculated by dividing the number of MEC items found (two) by the intrusively investigated portion of the high-anomaly-density area in which MEC may be present (3.25 acres). The estimated MEC density is 0.46 MEC per acre. Because only a small portion of the intrusive investigation results were included in that analysis, the MEC density may be an underestimate. This estimate was 40% lower than the density in the same area that was based on intrusive investigation of all anomalies, 0.78 MEC/acre, as reported in the Motlow RI Report. The two estimates differ by that amount because a 37mm projectile fuze MEC was found at one of the anomalies that was not selected to be investigated based on the TEMTADS data.

7.12.3 Extent of Munitions and Explosives of Concern Contamination

The RI estimated the horizontal extent of MEC contamination based on the results of the EM61 transects and the intrusive investigation within the high density areas. The classification characterization approach concluded that MEC may be present within high-density Areas 4, 5, 6, and 9. The four potentially contaminated grids are within one high-anomaly-density area. The extent of MEC contamination is therefore the extent of the high-anomaly-density area where the MEC were found. This is the same conclusion reported in the revised conceptual site model. The RI report also listed an additional area of MEC contamination that contained 60-mm mortar MEC. This area was not part of the technology demonstration because the wet ground conditions at the time of the TEMTADS field work made accessing the area difficult.

7.12.4 Depth of Munitions and Explosives of Concern Contamination

Based on the limited number of intrusive investigations selected using TEMTADS data, the depths of MEC at the site were determined to be 51 cm for the 155-mm projectile and 11 cm for 37-mm projectiles. These were within 25% of the RI report conclusions of 51 cm for 155-mm projectiles and 12 cm for 37-mm projectiles. The deeper conclusion reached in the RI report was based on the recovery depth of one 37-mm sized MEC item that was found at a grid not visited with the TEMTADS sensor.

7.12.5 Site Characterization Evaluation

The site characterization conclusions based on limited intrusive investigations matched the results reported in the Motlow RI report in three of the four evaluated above, meeting the success criteria for the project but not the performance objective.

8.0 COST ASSESSMENT

The cost assessment was split into two groups: TEMTADS costs and conventional intrusive costs. The TEMTADS costs include instruments, surveying, seeding, and analysis costs; the conventional intrusive costs include surface sweep, data collection, and intrusive costs.

8.1 COST MODEL

The cost model for the Motlow RI demonstration includes the total cost of the project and potential savings from the classification process. The total cost includes the seeding operation, TEMTADS operations, processing, and intrusive operation. Estimates for each operation are listed in Table 8-1.

Although the TEMTADS sensor used for data collection at Motlow was funded by ESTCP, standard rental costs and prep fees were used to determine the cost for the Motlow project had Parsons rented the sensor for the duration of the project. Weekly costs for equipment on a typical project were calculated using only items that would be required each week and not items like mobilization, prep, or shipping fees that would be one-time items on most projects. Survey and analysis costs were tracked using a task-specific number in Parsons' project controls system.

The final result of the classification process provides an alternative approach to the final costs of the intrusive operations. The analysis compares costs of using TEMTADS vs. digging all anomalies classified as no-digs. At Motlow, classification eliminated 65% of digs at a cost of approximately $61 per target. The overall cost of excavating the 794 TEMTADS anomalies was approximately $95,580 ($120/anomaly).

Table 8-1: Details of the Tracked Costs

Cost Element	Data Tracked During Demonstration	Estimated Costs
Seeding/EM61 Survey Costs		
Seed emplacement/initial set up	Costs for surface sweep, seed emplacement, surveying seeds	$35,485
Survey costs	The survey costs will include the time spent in the field collecting and recording data	$33,287
TEMTADS Survey Costs		
Instrument costs	TEMTADS Rental ($500/day; 14 days) TEMTADS Prep Fee (project) TEMTADS Shipping (project) RTK GPS Cost ($800/week; 2 weeks) Shipping (RTK GPS, etc; project) **Total** Per Target	$7,000 $1,000 $2,700 $1,600 $324 **$12,264** $13.58
Survey costs	Field-related labor (2 geophysicists, UXO Technician II), equipment set-up, test pit data collection, cued data collection, preprocessing, initial target inversion for QC checks, non-equipment direct costs (per diem, hotel, fuel, and etc.) Per target	$34,512 $38.22
Analysis costs	All processing and analysis performed following the completion of field activities Per target	$8,307 $9.20
Intrusive Costs		
Investigations	All costs related to the intrusive investigation Cost per anomaly to intrusively investigate	$95,580 $120

8.2 COST DRIVERS

Based on the factors described above, the total per target cost for the TEMTADS-related work at Motlow was approximately $61. Parsons considers this a fairly significant overestimation of the actual costs that would be necessary for future projects based on the following factors specific to Motlow:

- Training was required for field team that was somewhat unfamiliar with the TEMTADS.
- Unfamiliarity also led to a significant number of re-shots during the first week of the project.
- A hardware problem related to the TEMTADS transmitter resulted in a significant number of down days for the instrument.

When the TEMTADS worked as planned, the field team was able to collect a maximum of 187 points per day. However, the issues discussed above resulted in an average production rate of only 102 points per day. The TEMTADS hardware problem was, by far, the largest cause of the relatively low production, with significant portions of some days spent trying to fix the problem. Once fixed, a production rate of twice that achieved at Motlow is not out of the question.

For the intrusive investigation phase at Motlow, Parsons investigated the 794 anomalies in 10 intrusive days. The average anomalies intrusively investigated per day was 80 anomalies. The most common item excavated at Motlow was fragments. Efficiency among the intrusive teams was the main factor in the production or lack of production throughout the project.

- The predetermined path of processing a group of anomalies that require the least amount of movements for the intrusive teams with all their equipment was the single most important factor in production.
- Multiple-contact anomalies were frequently based on the low EM61 threshold for QC; identifying fragments and barbed wire pits early potentially saved intrusive time.
- Moving personnel and equipment between the six isolated investigation areas was very time consuming, but proper planning minimized this need.
- Working in wheat fields while the crops grew tall enough to obscure the pin flags marking target locations slowed the reacquisition and intrusive operations.
- Pinpointing small anomalies quickly with the EM61 minimizes standby time of the actual digging; small fragments were difficult to locate with the wide EM61 sensor. Having an experienced EM61 operator helped this process.
- The weather was a big factor during the summer; areas with no shade required more breaks and water intake for the intrusive teams.

8.3 COST BENEFIT

For a production removal action project with 10,000 anomalies selected for investigation, we would expect the TEMTADS costs to be reduced to approximately $41/anomaly (based on a production rate of 200/day) for data collection and processing. We would also expect the intrusive costs to be closer to $100/anomaly. Assuming a 65% reduction in the number of clutter items that could be eliminated from intrusive investigation would yield a potential cost savings of $240,000 based on the following assumptions:

- 10,000 anomalies at $100/anomaly for intrusive investigation equals a cost of $1,000,000.
- Reduction of 6,500 anomalies at $100/anomaly equals a reduction of $650,000 in excavation costs.
- TEMTADS costs for analyzing 10,000 anomalies at $41/anomaly equals a cost of $410,000.
- Total net savings under this scenario equals $240,000 (24%).

9.0 IMPLEMENTATION ISSUES AND LESSONS LEARNED

The few implementation issues noted on the project are described below:

- A faulty transmitter in the TEMTADS needed to be replaced during the first week of field work. Diagnosis of the problem and replacement of the transmitter took approximately 6 days.
- Two hundred fifty-two TEMTADS points were identified as targets that should be re-shot due to fit locations in the original data farther than 40 cm from the collection point. The high percentage of re-shots (22%) can be attributed to the fact that only the first 81 flags were located on the peak EM61 response, while the remaining flags were placed over the picked EM61 points. The remaining flags had to rely on the real-time inversion function to accurately pinpoint the anomaly location. As a result, more anomaly locations had to be recollected because they were not placed over the peak EM61 response. However, most of these recollected points were collected efficiently because the team used the in-field inversion to identify necessary recollects and did not have to return to the point.
- There are two potential solutions to the small ISO incorrectly classified as a non-dig:
    1) Classifying anything that passed the confidence metric thresholds as a dig regardless of distance from the sensor. Applying this logic would have added 26 digs to dig list 1, resulting in the detection of all TOI and a 66% reduction in clutter digs instead of a 70% reduction.
    2) Performing reacquisition with an EM61 prior to TEMTADS collection. By reacquiring the anomalies with an EM61, the TEMTADS would have been placed more directly over the small TOI resulting in more reliable classification data.

  The reacquisition survey would likely be worthwhile given an increase in data quality overall, fewer re-shots, and fewer instances where a decision would need to be made regarding things modeling outside of the sensor radius.

10.0 REFERENCES

Parsons, 2013. *ESTCP Munitions Response Pilot Study Plan, TEMTADS MP 2x2 at Motlow Range*, February.

U.S. Army Corps of Engineers, 2004. *Archives Search Report Supplement*.