ESTCP Live Site Demonstrations
Former Spencer Artillery Range

Spencer, TN

ESTCP MR-1165
Demonstration Data Report
Former Spencer Artillery Range
TEMTADS Demonstration

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Acronyms

Abbreviation	Definition
AOL	Advanced Ordnance Locator
APG	Aberdeen Proving Ground
ASCII	American Standard Code for Information Interchange
ATC	Aberdeen Test Center
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
DAS	Data Analysis System
DGPS	Differential GPS
EMI	Electro-Magnetic Induction
ESTCP	Environmental Security Technology Certification Program
FQ	Fix Quality
GPS	Global Positioning System
HASP	Health and Safety Plan
IDA	Institute for Defense Analyses
IMU	Inertial Measurement Unit
IVS	Instrument Verification Strip
MP	Man-Portable
MPV2	Man-Portable Vector Sensor, version 2
MR	Munitions Response
MTADS	Multi-sensor Towed Array Detection System
NMEA	National Marine Electronics Association
NRL	Naval Research Laboratory
POC	Point of Contact
(PTNL,)AVR	Time, Yaw, Tilt, Range for Moving Baseline RTK NMEA-0183 message
(PTNL,)GGK	Time, Position, Position Type, DOP NMEA-0183 message
QC	Quality Control
RMS	Root-Mean-Squared
RTK	Real Time Kinematic
Rx	Receiver
SAIC	Science Applications International Corporation
SERDP	Strategic Environmental Research and Development Program
SLO	San Luis Obispo
SNR	Signal-to-Noise Ratio
TEM	Time-domain Electro-Magnetic
TEMTADS	Time-domain Electro-Magnetic MTADS
TOI	Target of Interest
Tx	Transmit(ter)
UXO	Unexploded Ordnance

1.0 INTRODUCTION

1.1 ORGANIZATION OF THIS DOCUMENT

The results of the Naval Research Laboratory (NRL) Time-domain Electromagnetic Multi-sensor Towed Array Detection System (MTADS), or TEMTADS, demonstration as part of the Environmental Security Technology Certification Program (ESTCP) Live Site Demonstrations at the former Spencer Artillery Range, located in Spencer, TN in May 2012 are presented in this document. To limit the repetition of information, Study- and site-specific information that are presented elsewhere, such as in the ESTCP Live Site Demonstrations Plan [1], are noted and not repeated in this document.

1.2 STUDY BACKGROUND AND OBJECTIVES

Please refer to the ESTCP Live Site Demonstrations Plan [1].

1.3 SPECIFIC OBJECTIVES OF DEMONSTRATION

As part of NRL's ESTCP-funded Live Site Demonstrations, NRL conducted four advanced Electromagnetic Induction (EMI) surveys within the 9.4-acre demonstration site. These surveys were conducted using both the NRL TEMTADS 5x5 Array (5x5 Array) and TEMTADS MP 2x2 Cart (MP System). The TEMTADS 5x5 Array was used to conduct cued data collection for 1,168 anomalies in the Open Area for UXO/Clutter classification. The MP System was used for cued data collection for 714 anomalies in the Wooded Area and for 389 anomalies in the Dynamic Area. Prior to cued data collection in the Dynamic Area, a dynamic data collection was conducted with the MP System. Characterization of system response to the Targets of Interest (TOIs) was augmented with onsite measurements to supplement existing libraries. These data were collected in accordance with the overall study objectives and demonstration plan.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 TEMTADS EMI Sensors

Two types of advanced EMI sensors are discussed in this document. The first is the EMI sensor developed for the 5x5 Array under ESTCP project MR-200601 and described in the next paragraph, consisting of a single transmitter loop coaxially located with a single vertical-axis receiver loop. The second is the 'TEMTADS/3D' sensor in which the same transmitter coil is used but the receiver coil is replaced by an 8 cm, 3-component 'cube' receiver that was first developed by G&G Sciences under a Navy-funded project known as the Advanced Ordnance Locator (AOL). NRL have developed systems made from multiple copies of these sensors, assembled in a variety of array configurations. Minor modifications were made to the AOL control and data acquisition infrastructure to make it compatible with our deployment schemes.

A photograph of a standard TEMTADS sensor element (as used in the MR-200601 array) is shown under construction in the left panel of Figure 2-1. The transmit (Tx) coil is wound around the outer portion of the form and is 35 cm on a side. The receive coil is wound around the inner part of the form which is re-inserted into the outer portion and is 25 cm on a side. 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.

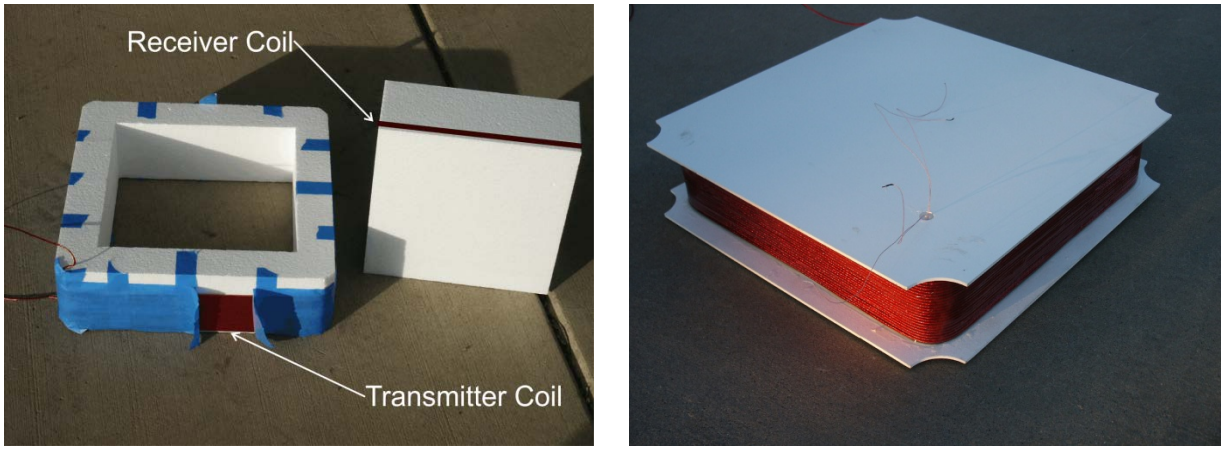

Figure 2-1 – Construction details of an individual standard TEMTADS EMI sensor (left panel) and the assembled sensor with end caps attached (right panel).

Decay data are collected with a 500 kHz sample rate until 25ms after turn off of the excitation pulse. A raw decay consists of 12,500 points; too many to be used practically. These raw decay measurements are grouped into 122 logarithmically-spaced "gates" with center times ranging from 25 μs to 24.375 ms with 5% widths and the binned values are saved to disk. Examples of the measured transmit pulse, raw decay, and gated decay are shown in Figure 2-2.

The individual TEMTADS EMI sensor (consisting of transmit electronics, transmit and receive coils, pre-amp, and digitizer) was characterized at G & G Sciences before approval was given for construction of the 5x5 Array. Examples of the characterization data are shown in Figure 2-3 and Figure 2-4. System stability is demonstrated in Figure 2-3 which plots the normalized (by measured transmit current) response of a 2-in steel ball at a 25 cm separation from the sensor. The data plotted are decays 1, 1001, 2001, and 3001 in a continuously-triggered series that began from a cold start and ran for 2.5 hours. For comparison purposes, the expected response from this sphere is plotted in black. As can be seen, the sensor exhibits excellent stability which will be important for the cued deployment planned.

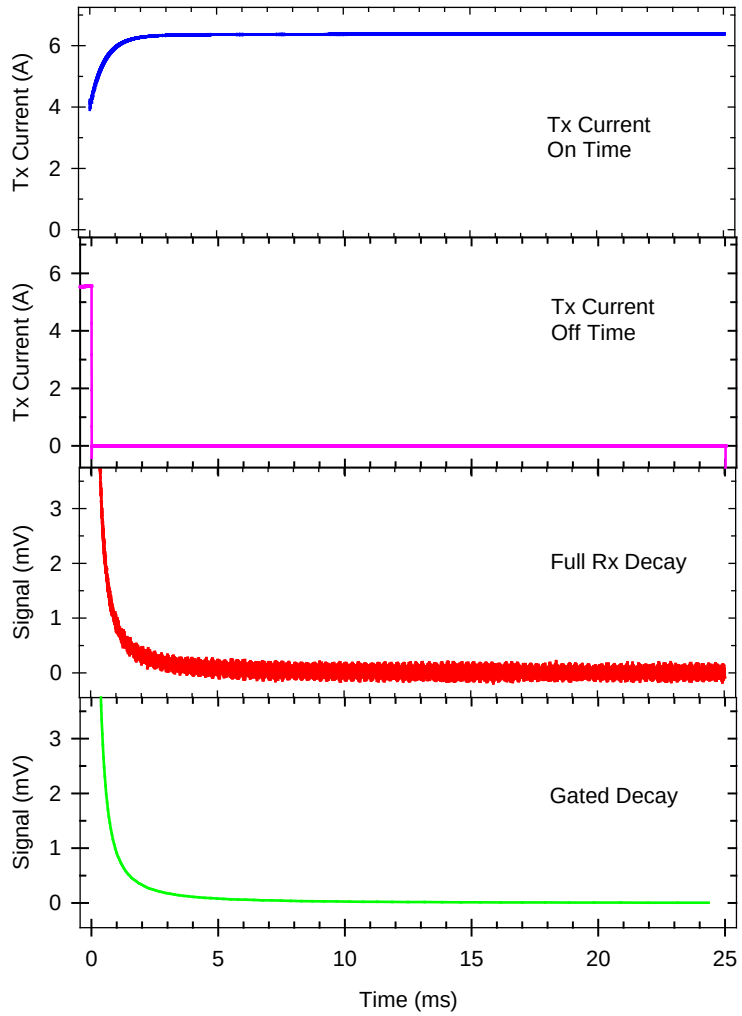

Figure 2-2 – Measured transmit current (on-time upper panel, off-time second panel), full measured signal decay (third panel), and gated decay (fourth panel) as discussed in the text.

The second important characterization test is sensor response linearity. Since we collect decay data to late times and over several orders of magnitude in amplitude, the linearity of system response is very important. To characterize this property of the sensor, we constructed a series of copper coils with nominal decay time constants of 2, 4, and 6 ms. The responses of the three coils are shown in Figure 2-4 which plots the measured decays on a semi-log axes. After a transient at early times, the decays exhibit clean exponential behavior with measured decay times of 1.8, 3.3, and 5.8 ms. Careful calculation of the expected decay times at the temperature at which the tests were conducted results in expected values of 1.82, 3.26, and 5.73 ms; the measured values are in excellent agreement with these.

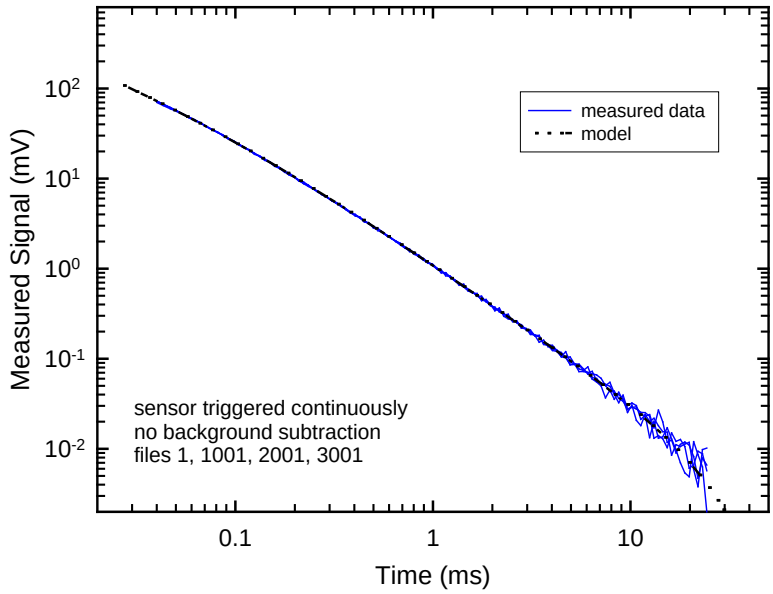

Figure 2-3 – Measured response from a 2-in steel sphere placed 25 cm from the sensor. Decays 1, 1001, 2001, and 3001 from a series that started from a cold start are plotted along with the expected response from this target.

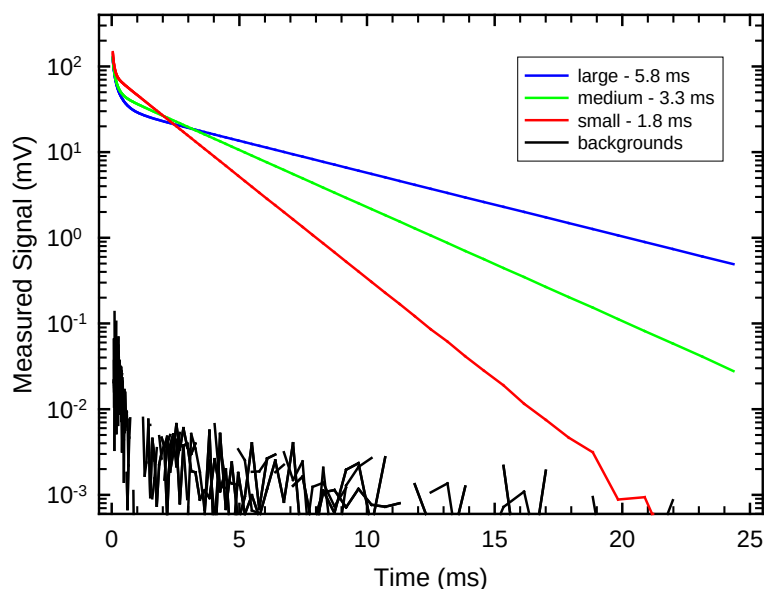

Figure 2-4 – Measured response from three calibration coils and the background response between measurements plotted on a semi-log plot to emphasize the exponential nature of the decay. The decay time constants extracted from the measurements are listed in the legend.

2.1.2 TEMTADS/3D EMI Sensor

The original design of the MP system utilized the standard TEMTADS EMI sensor. Based on the results of the MP system demonstration at the APG Standardized UXO Test Site in August, 2010 [2], revision of the sensor technology was indicated. A modified version of the sensor element was designed and built, replacing the single, vertical-axis receiver coil of the original sensor with a three-axis receiver cube. These receiver cubes are similar in design to those used in the second-generation AOL and the Geometrics MetalMapper (ESTCP MR-200603) system with dimensions of 8 cm rather than 10 cm. The CRREL MPV2 system (ESTCP MR-201005) uses an array of five identical receiver cubes and a circular transmitter coil. The new sensor elements are designed to have the same form factor as the original, aiding in system integration. A new coil under construction is shown in Figure 2-5.

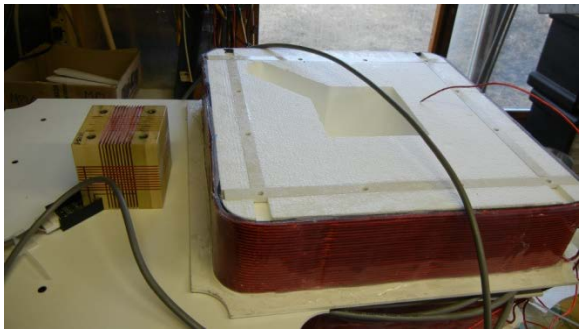

Figure 2-5 – Individual TEMTADS/3D EMI sensor with 3-axis receiver under construction.

2.1.3 Application of the Technology

Application of these technologies is straightforward. A list of target positions is developed from some source. In the case of this demonstration, the anomaly list was derived from EM61-MK2 data collected by URS Corporation (URS). Anomaly selection was conducted by URS and checked for data quality assurance by US Army Corps of Engineers (USACoE), Huntsville staff. Anomaly lists for each survey area were provided by URS to the ESTCP Program Office. For the 5x5 Array, a target file, containing the target location and an optional flag for additional 'stacking' or averaging, for each anomaly was transferred to the system control program. The program uses the information provided from the three GPS antennae to guide the operator to position the array over each target in turn. For the MP system, flags were manually placed over each anomaly location in advance. When the system was positioned over the target, the transmitter for each array sensor was fired in sequence, and decay data were collected from all receive coils for each excitation. These data were then stored electronically on the data acquisition computer. For the 5x5 Array, a few seconds of platform position and orientation data were collected at the end of the EMI data collection. The inverted position determined for each anomaly is initially relative to the array center. For the 5x5 Array, the recorded position and orientation data were used to translate the local position into absolute position and orientation. Prior to moving to the next target, the operator evaluated a display of the monostatic signal

amplitudes at an early time gate (42 μs for the 5x5 Array) and compared the values to a 'low SNR' threshold (nominally 5 mV/Amp). If no amplitude was above the threshold, the operator could elect to collect additional data for the target prior to leaving the target location.

In the next version of this technology, the facility for conducting a 'quick and dirty' inversion prior to the operator moving the array to the next target will be implemented. For this demonstration, the inversions were performed off-line so that we had the ability to intervene in the data processing pipeline as required. The EMI and position data were transferred to the analyst several times each day for near real-time analysis at the demonstration site.

2.1.4 Development of the Technology

The Chemistry Division of NRL has participated in several programs funded by SERDP and ESTCP whose goal has been to enhance the discrimination ability of MTADS for both magnetometer and EMI array configurations. The process was based on making use of both the location information inherent in an item's magnetometry response and the shape and size information inherent in the response to the time-domain electromagnetic induction (EMI) sensors that are part of the baseline MTADS in either a cooperative or joint inversion. In these past efforts, our classification ability has been limited by the information available from the time-domain EMI sensor. Further information regarding the MTADS magnetometer and EM61 sensor arrays can be found in Reference 3 and the references within.

To make further progress on UXO classification, a sensor with more available information was required. The Geophex, Ltd. GEM-3 is a frequency-domain EMI sensor with up to ten transmit frequencies available for simultaneous measurement of the in-phase and quadrature response of the target. In principle, there is much more information available from a GEM-3 sensor for use in discrimination decisions. However, the commercial GEM-3 sensor is a hand-held instrument with relatively slow data rates and is thus not very amenable to rapid, wide area surveys. ESTCP Project MM-0033, Enhanced UXO Discrimination Using Frequency-Domain Electromagnetic Induction, was funded to overcome this limitation by integrating an array of GEM-3 sensors with the MTADS platform [4]. Further details can be found in References 3 and 4.

Reference 5 compares the detection-only performance of the magnetometer, the second-generation MTADS EM61-MK2, and the GEMTADS arrays to other demonstrators at both of the Standardized UXO Technology Demonstration Sites. All three sensor arrays were also demonstrated in the Spring of 2007 as part of the ESTCP UXO Discrimination Study at the former Camp Sibert [3]. The magnetometer and EM61-MK2 sensor arrays were demonstrated in the Spring of 2009 as part of the ESTCP UXO Classification Study at the former Camp San Luis Obispo (SLO) [6].

Under SERDP project MM-1315 (EMI Sensor Optimized for UXO Discrimination) and ESTCP project MR-200601, NRL, SAIC, and G&G Sciences have developed a time-domain EMI sensor optimized for the classification of UXO. The 5x5 Array was constructed in 2007 and field tested at the APG Standardized UXO Test Site in June 2008 [7]. After processing, ranked dig lists were generated and submitted to ATC for scoring. The results of the demonstration, as scored by

ATC are available in Reference 7. The 5x5 Array was also demonstrated as part of the 2009 ESTCP UXO Classification Study at the former Camp San Luis Obispo, CA [8] and as part of the 2010 ESTCP UXO Classification Study at the former Camp Butner, NC [9]. The 5x5 Array and MP System were demonstrated as part of the 2011 ESTCP Munitions Response Live Site Demonstration [10,11]. The results of the APG and SLO demonstrations are discussed in the ESTCP MR-200601 Project Final Report [12].

The MP System is a man-portable four-element transient EMI system designed and built by the NRL with funding from ESTCP to transition the TEM sensor technology of the 5x5 Array (ESTCP Project MR-200601) to a more compact, man-portable configuration for use in more limiting terrain under project MR-200909. Like the towed array, this system was initially configured to operate in a cued mode, where the target location is already known. Preliminary testing of the initial system configuration [13] found that for high SNR ($\geq$ 30) targets one measurement cycle provided enough information to support classification. For deeper and/or weaker targets, more robust estimates of target parameters were obtained by combining two closely-spaced measurements. Two measurements per anomaly were typically made proactively to avoid the potential need to revisit a target a second time. As part of project MR-200909, a demonstration was conducted to rigorously investigate the capabilities of this new sensor platform for UXO classification in a cued data collection mode at the APG Standardized UXO Test Site in August, 2010 [14]. Those results indicated that the inversion performance of the system was not comparable to that of the full 5x5 array for lower SNR targets due to the limits of the smaller data set (fewer looks at the target). Revision of the sensor technology was indicated for the MP system to collect sufficient data over an anomaly. A modified version of the EMI sensor was designed and built, replacing the single, vertical axis receiver loop of the original coil with a tri-axial receiver cube. These receiver cubes are identical in design to those used in the CRREL MPV2 system (ESTCP MR-201005). The new sensor elements were designed to have the same form factor as the originals, aiding in system fabrication. The completed MP system was demonstrated as part of the ESTCP Munitions Response Live Site Demonstrations at the former Camp Beale, CA in June, 2011 [10].

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The 5x5 Array was designed to combine the data quality advantages of a gridded survey with the data coverage efficiencies of a vehicular system. The resultant data should therefore be equal, if not better, in quality to the best gridded surveys (the relative position and orientation of the sensors will be better than gridded data) while prosecuting many more targets each field day.

There are obvious limitations to the use of this technology. The 5x5 Array is 2-m square in area and mounted on a trailer. Fields where the vegetation or topography interferes with passage of a trailer of that size will not be amenable to the use of the present array. The other serious limitation is anomaly density.

The MP System was designed to offer similar production rates in difficult terrain and treed areas that the 5x5 Array cannot access. With the upgraded TEMTADS/3D sensors, similar performance was achieved with similar classification-grade data quality. The MP array is 80 cm

on a side and mounted on a man-portable cart. Terrain where the vegetation or topography interferes with passage of a cart of that size will not be amenable to the use of the system.

For all systems, there is a limiting anomaly density above which the response of individual targets cannot be separated individually. We have chosen relatively small sensors for this array which help mitigate this problem but we cannot eliminate it completely. Recent developments, including solvers designed for classification in multiple-object scenarios such as SAIC's multi-target solver, [15] are being evaluated and their performance characteristics in cluttered environments determined.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for the demonstration are given in Table 3-1 to provide a basis for evaluating the performance and costs of the demonstrated technology. These objectives are for the technologies being demonstrated only. Overall project objectives were given in the overall demonstration plan generated by ESTCP. The objectives are divided into two parts, dynamic survey-specific objectives and objectives for all data collection.

3.1 ALONG-LINE MEASUREMENT SPACING

The value of the collected dynamic data depends on the extent of coverage of the site that it represents. Gaps in coverage impede or prevent analysis of the data. This objective concerns the ability to collect dynamic data with acceptable along-line data density.

3.1.1 Metric

The metric for this objective was the percentage of data points within acceptable along-line spacing. Provisions for exceptions based on topology / vegetation interferences were made, but not required.

3.1.2 Data Requirements

A mapped data file was used to judge the success of this objective.

3.1.3 Success Criteria

This objective was considered met if at least 98% of the mapped data points were within 25 cm of the neighboring data points along the survey line. The acceptable along-line spacing was increased from the 15 cm specified for the EM61-MK2 in Reference 1 to 25 cm due to the data rate of the MP system.

Table 3-1 – Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Dynamic Survey			
Along-line measurement spacing	Point-to-point spacing from data set	Mapped survey data	98% < 25 cm along-line spacing
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	Calculated using UXProcess Footprint Coverage QC Tool and a sensor footprint of 80cm
Detection of all targets of interest (TOI)	Percent detected of seeded items	Location of seeded items Anomaly List	100% of seeded items detected within a 60 cm halo
All Surveys			
Instrument Verification Strip (IVS) Results	Fit results from each emplaced item Measured locations of emplaced items	Daily IVS data	Down-track location ±10 cm Polarizabilities: βs ±10%
Cued interrogation of anomalies	Instrument position	Cued survey data	100% of anomalies where the center of the instrument is positioned within a given distance of the actual target location
			TEMTADS 5x5: 60 cm
			TEMTADS 2x2: 40 cm

3.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The value of collected survey data depends on the extent of coverage of the site. This objective concerns the ability to completely survey the site and obtain sufficient data coverage. Provisions for exceptions based on topology / vegetation interferences were made, but not required.

3.2.1 Metric

The metric for this objective was the footprint coverage as measured by the UXProcess Footprint Coverage QC tool.

3.2.2 Data Requirements

A mapped data file was used to judge the success of this objective.

3.2.3 Success Criteria

This objective was considered met if the survey achieved at least 85% coverage at 0.5-m line spacing and 98% at 0.75-m line spacing, as determined using the UX-Process Footprint Coverage QC tool.

3.3 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST (TOI)

The collection of quality data should lead to a high probability of detecting the TOI at the site.

3.3.1 Metric

The metric for this objective was the percentage of seed items that were detected using the specified anomaly selection threshold.

3.3.2 Data Requirements

Each demonstrator prepared an anomaly list. USACoE personnel evaluated the detection probability of the seeded items as part of their data Quality Assurance (QA) review.

3.3.3 Success Criteria

The objective was considered to be met if 100% of the seeded items were detected within a halo of 60 cm.

3.4 OBJECTIVE: INSTRUMENT VERIFICATION STRIP (IVS) RESULTS

This objective demonstrates that the sensor system was in good working order and collecting physically valid data each day. The Instrument Verification Strip (IVS) was surveyed twice daily. The amplitudes of the derived response coefficients for each emplaced item were compared to the running average of the demonstration for reproducibility. The extracted fit locations of each item were compared to the reported ground truth and the running average of the demonstration.

3.4.1 Metric

The reproducibility of the measured responses of the sensor system to the emplaced items and of the extracted locations of the emplaced items defines this metric.

3.4.2 Data Requirements

The tabulated fit parameters for the data corresponding to each emplaced item in terms of derived response coefficients, location, and depth.

3.4.3 Success Criteria

The objective was considered met if the RMS amplitude variation of the derived response coefficients was less than 10% and the down-track fit location of the anomaly was within 10 cm of the corresponding seeded item's stated location.

3.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

To collect EMI data of the highest quality for UXO/clutter classification, the anomaly must be illuminated along its three principle axes. To insure this, the data collection pattern (in this case the TEMTADS array) must be positioned directly over the center of the anomaly.

3.5.1 Metric

The metric for this objective was the percentage of anomalies where the center of the instrument was within the acceptable distance range from the actual target location.

3.5.2 Data Requirements

Demonstrators provided the ESTCP Program Office a weekly list of the location of the center of their instrument for each cued anomaly interrogated in the preceding week. The USACoE, Huntsville reviewed the offsets for the QC seeds and provide feedback to the demonstrator if their instrument was not within the acceptable distance. In the case of a failure, the demonstrator would have been required to reacquire data for those anomalies interrogated during the effected period and perform a root cause analysis for each failure.

3.5.3 Success Criteria

The objective was considered met for the 5x5 Array if the center of the instrument was positioned within 60 cm of the actual anomaly location for 100% of the cued anomalies. For the MP system, no global positioning is available. For the MP System, the criterion was that the fit location of the anomaly was within 40cm of the array center. The MP System criterion was empirically determined in the field during the former Camp Beale demonstration [10], based on array size alone. Examples can be found in collected data where high-fit-coherence inversions can be extracted from the data and the extracted magnetics polarizations provide a high-confidence classification match to objects located at the 40 cm limit. Counter examples also exist, especially for "on-edge" transmitter illumination cases. Detailed study using experimental data, modeling, or both would be required to determine an absolute "never-fail" threshold. It is anticipated that the result would be a threshold radius located in range of 25 – 30 cm.

4.0 SITE DESCRIPTION

Please refer to the ESTCP Live Site Demonstrations Plan [1].

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The demonstration was executed in three stages. The first stage was to characterize the TEMTADS platforms being demonstrated with respect to the site-specific TOI and to the site-specific geology. Measurements of site-specific TOI not already in our libraries were made on site, as discussed in Section 5.4.4. The site-specific geology was characterized through monitoring the background response of the demonstration site, as measured by the TEMTADS platforms, for the duration of data collection as discussed in Section 5.4.2

The second stage of the demonstration was a cued survey of the Open Area with the 5x5 Array and cued surveys of the Wooded Area with the MP System. In each area, the demonstrated system was positioned roughly over the center of each anomaly on the source anomaly list and a data set collected. Each data set was then inverted using the data analysis methodology discussed in Section 6.0, and estimated target parameters determined. The results and the archive data will then be submitted to the Program Office.

The third stage of the demonstration was a dynamic survey of the Dynamic Area, followed by data analysis to produce an anomaly list, followed by a cued survey of the resultant anomaly list. This set of surveys was conducted using the MP System.

The schedule of field testing activities is provided in Figure 5-1 as a Gantt chart.

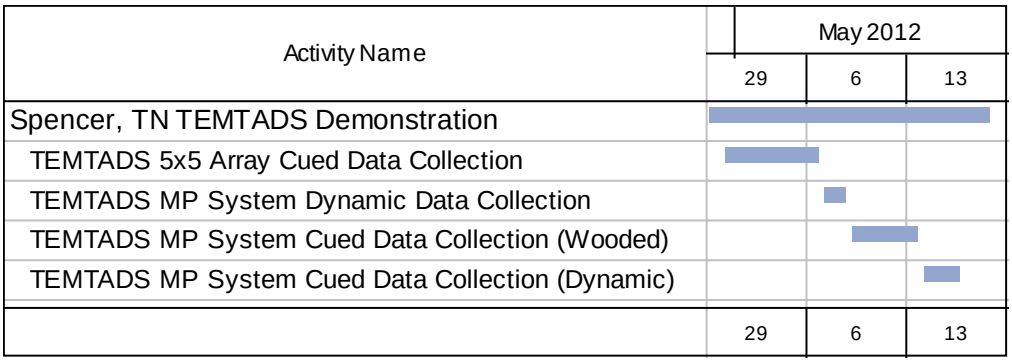

Figure 5-1 – Schedule of Field Testing Activities

5.2 SITE PREPARATION

Please refer to the ESTCP Live Site Demonstrations Plan [1].

5.3 SYSTEMS SPECIFICATION

This demonstration was conducted using the NRL MTADS tow vehicle and subsystems, the 5x5 Array, and with the MP System. Each component is described further in the following sections.

5.3.1 MTADS Tow Vehicle

The MTADS has been developed by NRL with support from SERDP and ESTCP. The MTADS hardware consists of a low-magnetic-signature vehicle that is used to tow sensor arrays over large areas (10 - 25 acres / day) to detect buried UXO. The MTADS tow vehicle and magnetometer array are shown in Figure 5-2.

Figure 5-2 – MTADS tow vehicle and magnetometer array.

5.3.2 RTK GPS System

Positioning is provided using cm-level Real Time Kinematic (RTK) Global Positioning System (GPS) receivers. To achieve cm-level precision, a fixed reference base station is placed on an established first-order survey control point near the survey area. The base station transmits corrections to the GPS rover at 1 Hz via a radio link (450 MHz). The 5x5 Array is located in three-dimensional space using a three-receiver RTK GPS system shown schematically in Figure 5-4 [16]. The three-receiver configuration extends the concept of RTK operations from that of a fixed base station and a moving rover to moving base stations and moving rovers. The lead GPS antenna (and receiver, Main) receives corrections from the fixed base station. This corrected position is reported at 10-20 Hz using a vendor-specific NMEA-0183 message format (PTNL,GGK or GGK). The Main receiver also operates as a 'moving base,' transmitting corrections (by serial cable) to the next GPS receiver (AVR1) which uses the corrections to operate in RTK mode.

A vector (AVR1, heading (yaw), angle (pitch), and range) between the two antennae is reported at 10 Hz using a vendor-specific NMEA-0183 message format (PTNL,AVR or AVR). AVR1 also provides 'moving base' corrections to the third GPS antenna (AVR2) and a second vector (AVR2) is reported at 10 Hz. All GPS measurements are recorded at full RTK precision, ~2-5

cm. For survey-mode arrays, typically one referenced the recorded positions to the GPS 1-PPS pulse output to fully take advantage of the precision of the GPS measurements. In this case of a cued survey, it is not necessary to address these timing issues. For the cued-mode survey, the GPS position is averaged for 2 seconds as part of the data acquisition cycle. The averaged position and orientation information are then recorded to the position (.gps, ASCII format) data file. The details of the file format are provided in Appendix C.

In dynamic mode, geolocation for the MP System is provided with a single RTK receiver mounted above the array center on a tripod. Centimeter-level positioning is provided at 20 Hz using a vendor-specific NMEA-0183 message format (PTNL,GGK or GGK). The MP system with the GPS-antenna tripod installed is shown in Figure 5-3.

Figure 5-3 – TEMTADS MP 2x2 Cart with GPS Antenna Tripod.
Photograph by Harry Wanger.

5.3.3 TEMTADS 5x5 Array

The 5x5 Array is comprised of twenty-five individual TEMTADS EMI sensors arranged in a 5 x 5 array, as shown in Figure 5-4. The center-to-center distance is 40 cm yielding a 2 m x 2 m array. The bottom of the array is positioned at a ride height of 17 cm above the ground, unchanged from the former Camp Butner, NC demonstration of 2010 [9]. The rationale of this array design is discussed in Reference 17. Sensor numbering is indicated in Figure 5-4. Also shown in Figure 5-4 is the position of the three GPS antennae that are used to determine the location and orientation of the array for each cued measurement. A picture of the array mounted on the MTADS EMI sensor platform is shown in Figure 5-5.

The transmitter electronics and the data acquisition computer are mounted in the tow vehicle. Custom software written by NRL provides both navigation to the individual anomalies and data acquisition functionality. After the array is positioned roughly centered over the anomaly, the data acquisition cycle is initiated. Each transmitter is fired in a sequence winding outward

clockwise from the center position (12). The received signal is recorded for all 25 receiver (Rx) coils for each transmit cycle. The transmit pulse waveform duration is 2.7s (0.9s block time, 9 repeats within a block, 3 blocks stacked, with a 50% duty cycle). While it is possible to record the entire decay transient at 500 MHz, we have found that binning the data into 122 time gates simplifies the analysis and provides additional signal averaging without significant loss of temporal resolution in the transient decays as discussed in Section 2.1.1 [18]. The data are recorded in a binary format as a single file with 25 data points (one data point per Tx cycle). The filename corresponds to the anomaly ID from the target list under investigation.

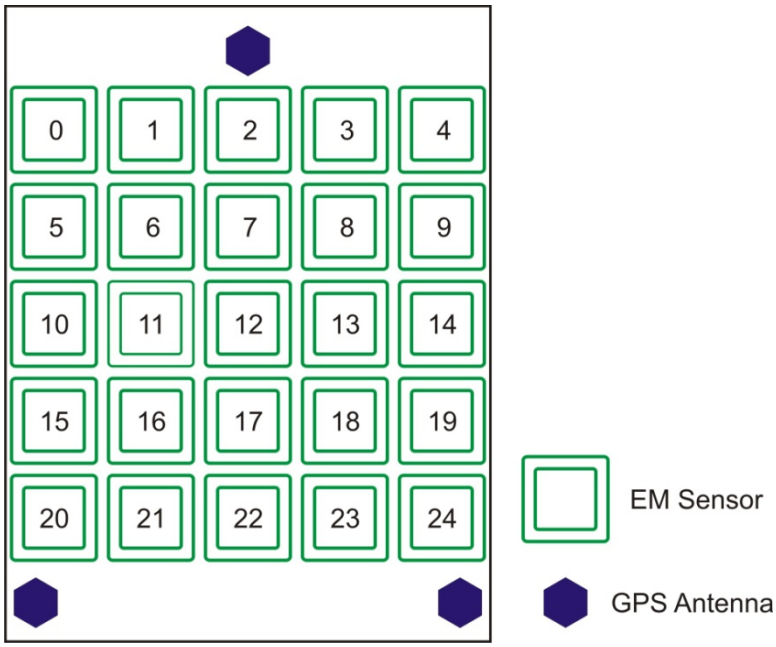

Figure 5-4 – Sketch of the EMI sensor array showing the position of the 25 sensors and the three GPS antennae.

Figure 5-5 – Sensor array mounted on the MTADS EMI sensor platform.

5.3.4 TEMTADS MP 2x2 Cart

The MP System is a man-portable system comprised of four of the TEMTADS/3D EMI sensors discussed in Section 2.1.2 arranged in a 2x2 array as shown schematically in Figure 5-6. The

MP system, shown in Figure 5-3 at the former Spencer Artillery Range, TN, is fabricated from PVC plastic and G-10 fiberglass. The center-to-center distance is 40 cm yielding an 80 cm x 80 cm array. The array is deployed on a set of wheels resulting in a sensor-to-ground offset of approximately 18 cm. The MP system can be operated in two modes: dynamic (or survey) mode and cued mode. In dynamic mode, a GPS antenna and (optionally) an inertial measurement unit (IMU) are mounted above the TEM array as shown in Figure 5-3. In cued mode, the locations of the anomalies are flagged for reacquisition in advance. In the future, the system will be configured to operate in a detection mode and to accept a target list of virtual flags and provide onboard navigation to the virtual flags in cued mode.

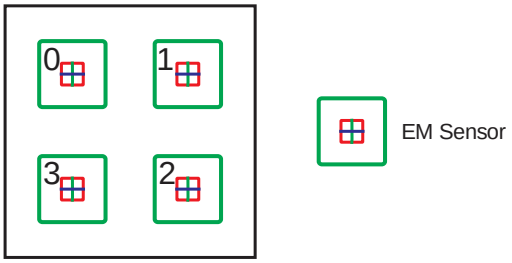

Figure 5-6 – Sketch of the EMI sensor array showing the position of the four sensors. The tri-axial, revised EMI sensors are shown schematically.

5.4 CALIBRATION ACTIVITIES

5.4.1 TEMTADS Sensor Calibration

For the TEMTADS family of platforms, a significant amount of data has been collected with the systems as configured at our Blossom Point facility, both on test stands, on our test field [19], and during our recent demonstrations at APG [7], the former Camp SLO [8], the former Camp Butner [9], the former Camp Beale [10], and the former Mare Island Naval Shipyard [11]. These data and the corresponding fit parameters provide us with 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 to determine the system background level for subtraction. These quiet spots were selected from the EM61-MK2 data and vetted with the TEMTADS systems prior to continued use. The items emplaced in the IVS were measured twice daily to monitor the variation in the system response. These two types of measurements constituted the daily calibration activities. Test pit measurements were made to determine the responses for site-specific TOI that were not already available in our reference library of TOI fit parameters.

5.4.2 Background Variation Data

A group of anomaly-free areas throughout the demonstration site were identified in advance from the EM61-MK2 data sets. Each background location was confirmed to be anomaly-free

prior to prolonged use with one of the TEMTADS systems. Any location found to exhibit an anomaly was discarded and not used further. Since the viable locations all provided roughly comparable responses, a convenient subset of the locations was chosen to be visited periodically throughout each day of the demonstration. All 87 background measurements taken for the duration of the Open Area survey (5x5 Array, April 30 – May 6, 2012) are shown in Figure 5-7, and are presented as the mean and standard deviation of the 25 monostatic measured signals. Dates are presented as Julian dates, or the day of the year. April 30, 2012 is Julian date 121. Table 5-1 tabulates the intraday variations of the mean and standard deviation quantities from Figure 5-7. Dates 125, 126, and 127 show significantly higher initial background values than the other dates. This was due to rain events overnight continuing into the morning.

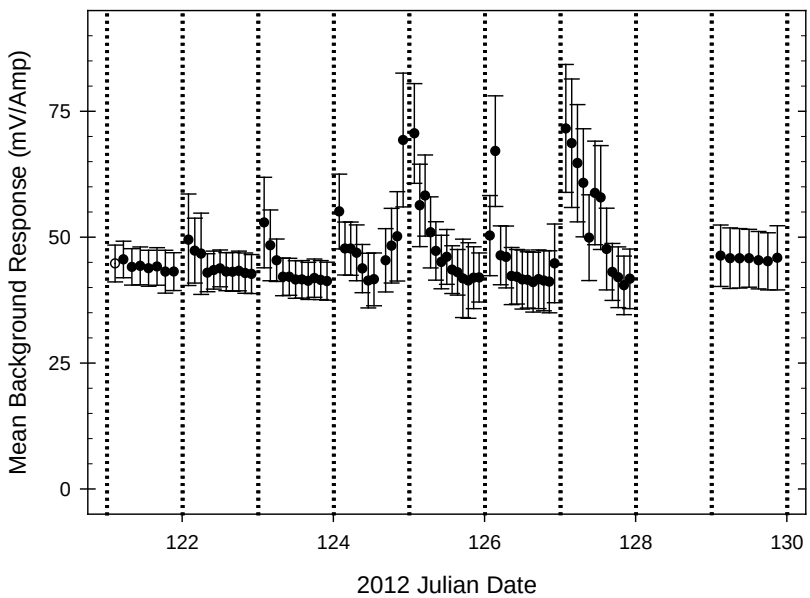

Figure 5-7 – Intra- and inter- daily variations in the response of the 5x5 Array to background anomaly-free areas through the duration of the Open Area survey. The points represent the average measured signal of the 25 monostatic values at 0.042 ms, while the bars represent the standard deviation of those quantities (i.e. 1σ about the mean).

Table 5-1 – Summary of the Daily Variation in the Mean and Standard Deviation of the Signals Measured at 0.042 ms for the 5x5 Array Background Areas.

Date	# of Bkgs.	Mean (mV/Amp)	Std. Dev. (mV/Amp)
4/30/2012	8	44.12	3.75
5/1/2012	11	44.42	4.93
5/2/2012	11	43.62	4.56
5/3/2012	12	48.83	6.80
5/4/2012	13	48.31	6.56
5/5/2012	13	45.16	6.55
5/6/2012	12	53.91	9.04
5/8/2012	7	45.73	5.92

All 94 background measurements taken for the duration of the Wooded and Dynamic Area cued surveys (MP system, May 9 - 16, 2012) are shown in Figure 5-8, and are presented as the mean and standard deviation of the four monostatic measured signals. Table 5-2 provides the intraday variations of the mean and standard deviation quantities of Figure 5-8. There was less diurnal variation in the MP system background levels as the background locations were located under tree cover and there were fewer rain events during the time period. One exception was midday on the May 14th (Julian date 135), where there was a brief rain event.

The R_x and R_y component responses, red and green in Figure 5-8 respectively, have similar standard deviations but are separated by a standard deviation. If the R_y components are broken out by sensor, there is a clear gradient from the front of the array towards the back of the array. This is shown in Figure 5-9. While the issue has not been systematically explored, the gradient in the R_y components is likely due to the location of the electronics backpack. The R_x components present a different spatial pattern, with the response being larger in magnitude on the right-hand side of the cart and alternating sign from front to back on both sides. These two trends lead to a consistently larger median value for the averaged R_y component response. For early time gates, such as the one used, subtle differences in construction can lead to differing influences of the transmitter shutdown transient as well. The effect is not consistent. No significant difference was seen at the former Camp Beale demonstration [10] and the effect was roughly half a standard deviation at the MMR [20] demonstration.

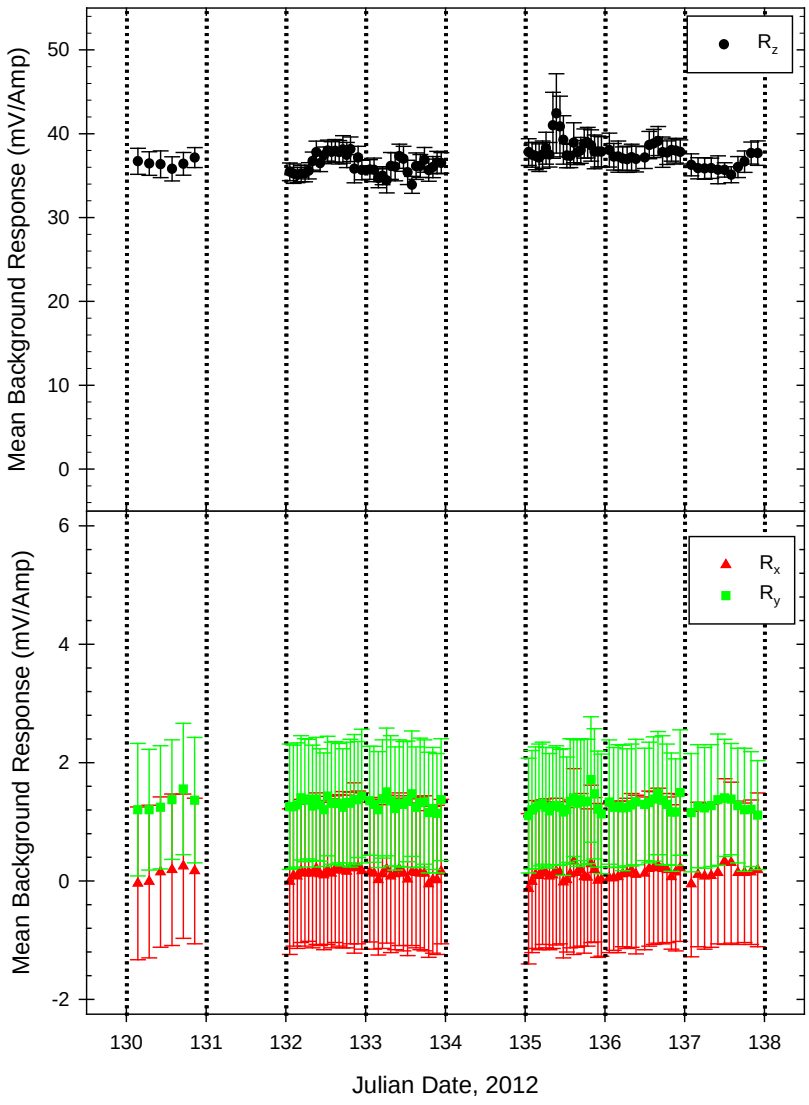

Figure 5-8 – Intra- and inter- daily variations in the response of the MP System to background anomaly-free areas through the duration of the demonstration. The upper panel plots the average measured signal of the four monostatic, Z-axis quantities at 0.089 ms, while the bars represent the standard deviation of those quantities (i.e. 1σ about the mean). The red and green points in the lower panel plot the average measured signal of the four monostatic, X- and Y-axis quantities at 0.089 ms, respectively.

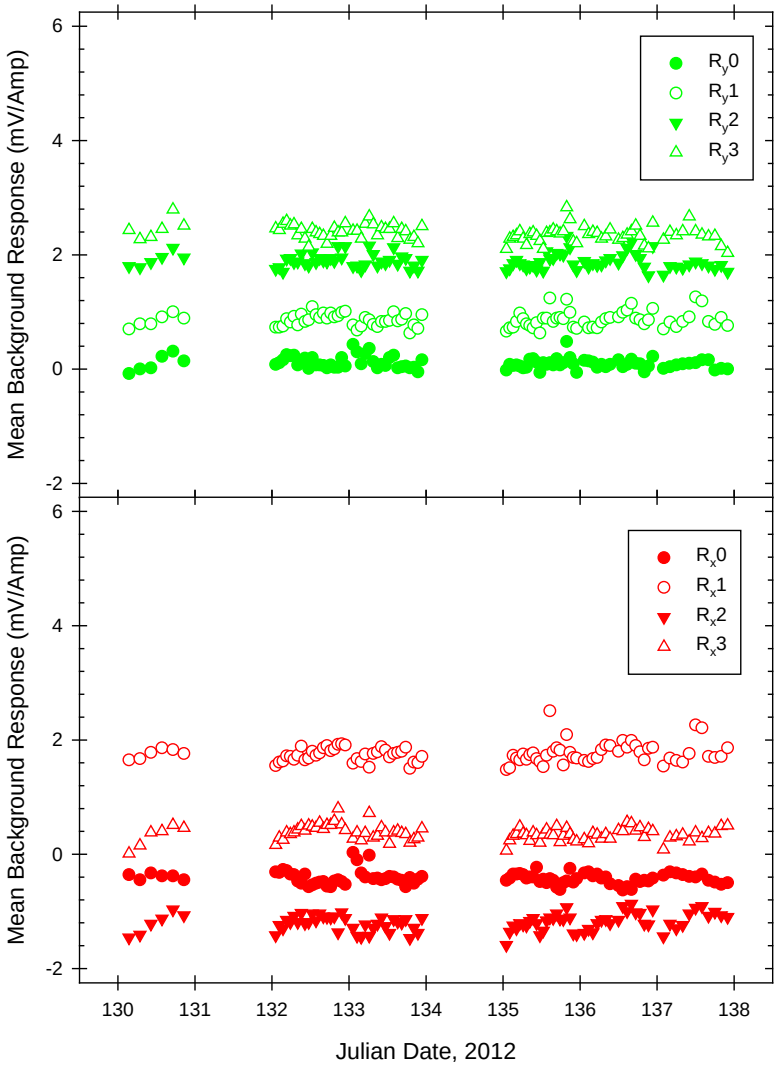

Figure 5-9 – Intra- and inter- daily variations in the response of the MP System to background anomaly-free areas through the duration of the demonstration. The upper panel plots the measured signal of the four monostatic, Y-axis quantities at 0.089 ms. The lower panel plots the measured signal of the four monostatic, X-axis quantities at 0.089 ms, respectively.

Table 5-2 – Summary of the Daily Variation in the Mean and Standard Deviation of the Signals Measured for the MP System Background Areas.

Date	# of Bkgs.	Mean Z (mV/Amp)	Std. Dev. Z (mV/Amp)	Mean Y (mV/Amp)	Std. Dev. Y (mV/Amp)	Mean X (mV/Amp)	Std. Dev. X (mV/A)
5/9/2012	6	36.48	1.42	1.33	1.06	0.12	1.26
5/11/2012	20	36.71	1.21	1.33	1.03	0.15	1.26
5/12/2012	18	35.85	1.35	1.31	1.03	0.10	1.26
5/14/2012	22	38.46	2.03	1.30	1.02	0.10	1.26
5/15/2012	17	37.17	1.67	1.31	1.02	0.15	1.27
5/16/2012	11	36.23	1.24	1.27	1.00	0.15	1.24

5.4.3 Instrument Verification Strip Data

The IVS was provided onsite to verify the repeatability of the response of each system to several examples of TOI. Details of the contents of the former Spencer Artillery Range IVS are given in Table 5-3. Each emplaced item in the IVS was measured twice daily, once before starting the data collection process and a second time before shutting the system down at the end of each day. Exceptions were made in the case of weather events ending the work day unexpectedly.

Table 5-3 – Details of Former Spencer Artillery Range IVS

ID	Description	Easting (m)	Northing (m)	Depth (m)	Inclination	Orientation
T-001	Shotput	635,344.10	3,939,129.12	0.30	N/A	N/A
T-002	37mm Projectile	635,344.18	3,939,125.12	0.15	Horizontal	Across Track
T-003	75mm Projectile	635,344.30	3,939,121.12	0.30	Horizontal	Across Track
T-004	Blank	635,344.27	3,939,117.14	N/A	N/A	N/A
T-005	(Small) ISO2	635,344.21	3,939,113.07	0.15	Horizontal	Across Track

All data sets for each of the emplaced IVS items were inverted using the data analysis methodology discussed in Section 6.0, and the estimated target parameters determined. As geolocation is not currently provided to the MP System in cued mode, only the variability in the inverted depth of each target was monitored for the MP System. We summarize the results in the following Sections.

5.4.3.1. TEMTADS 5x5 Array

For the 5x5 Array, thirteen measurements of the IVS were made. The RMS (1σ) variation in the amplitude at 0.042 ms in the decay was less than 5% of the mean amplitude for the primary polarizability and less than 7% for the secondary polarizabilities. Further details are given in Table 5-4 and shown in Figure 5-10. Except for the shotput, all RMS variations fell below 5% of the respective mean amplitudes. For a typical sphere, all three βs should be equal. The shotput used for this demonstration was purchased by URS and buried without characterization. The βs are clearly not equal and as shown in Figure 5-12 (right), the fit depths were ~7 cm shallow. The

description of the item[1] is "110mm Stainless Steel Shot Put." Without a second example to conduct in-air or pit characterization measurements on, it was not possible to determine the source of this consistent deviation from the typical sphere response. The 37mm projectile and the ISO2 both exhibit the expected axisymmetric $\beta_1 > \beta_2 \approx \beta_3$ relationship of UXO and other rod-like items. The 75mm projectile exhibits a crossover in behavior at early time, as shown in Figure 5-11. Thus, at 0.042 ms, the βs indicate a more plate-like response with $\beta_1 \approx \beta_2 > \beta_3$. At later times, the response relaxes to that of a rod-like object.

Table 5-4 – 5x5 Array Summary of the Amplitude Variations at 0.042 ms in the Derived Response Coefficients for Items Emplaced in the IVS.

Item	β_1 Amplitude (m^3)				β_2 Amplitude (m^3)				β_3 Amplitude (m^3)			
	Min	Max	Mean	RMS	Min	Max	Mean	RMS	Min	Max	Mean	RMS
Shotput	0.69	0.76	0.72	0.03	0.60	0.73	0.65	0.04	0.46	0.56	0.53	0.03
37mmP	0.29	0.32	0.30	0.01	0.25	0.30	0.28	0.01	0.25	0.30	0.28	0.01
75mmP	2.72	2.82	2.76	0.03	2.66	2.74	2.71	0.03	2.46	2.60	2.54	0.04
ISO2	0.77	0.83	0.79	0.02	0.56	0.59	0.57	0.01	0.53	0.58	0.55	0.02

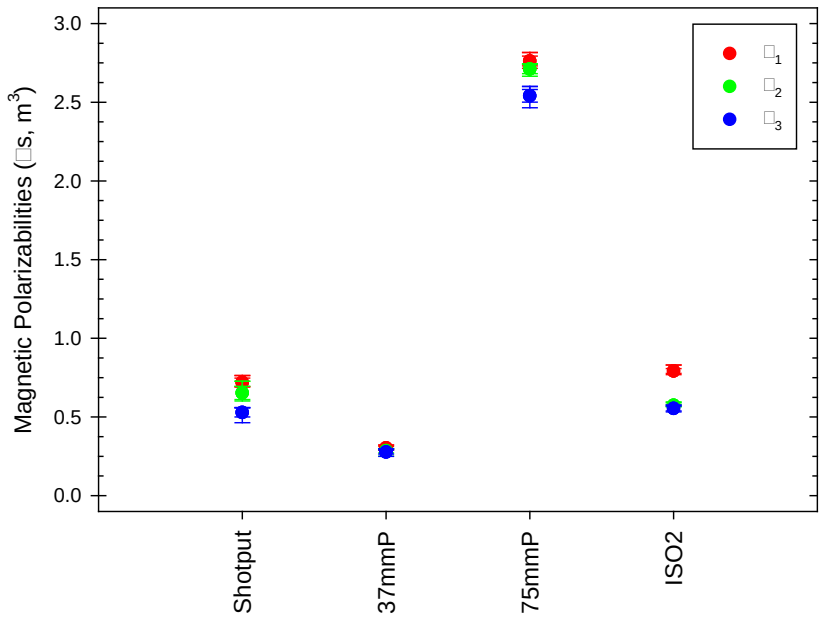

Figure 5-10 – 5x5 Array amplitude variations at 0.042 ms in the derived response coefficients for all items emplaced in the IVS. β_1 is in red; β_2 is in green; and β_3 is in blue.

[1] M-F Athletic, P/N 4463.
http://www.everythingtrackandfield.com/webapp/wcs/stores/servlet/Product1_10152_10754_2003054_-1

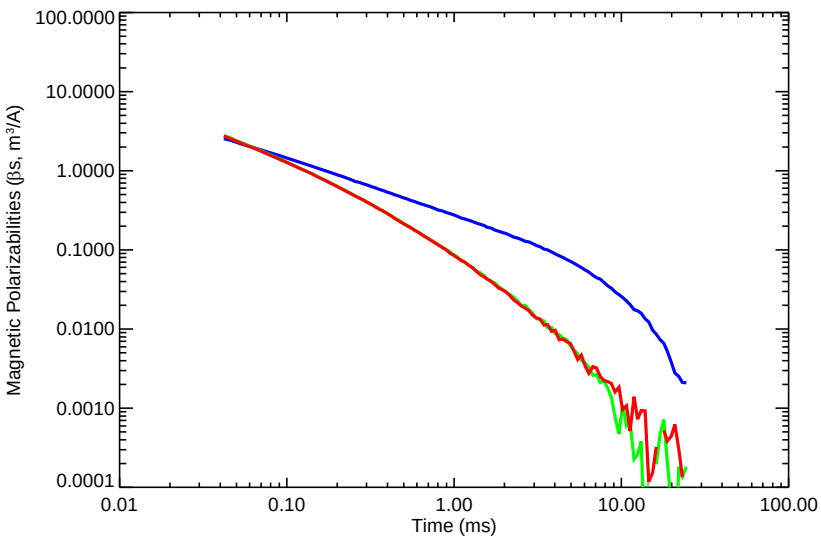

Figure 5-11 – Principal axis polarizabilities for a 75mm Projectile.

The aggregate horizontal position error statistics for the IVS items, as measured with the 5x5 Array, are listed in Table 5-5 and shown in the left panel of Figure 5-12. The position error is defined as the fit position (or, equivalently, the inverted position parameter) minus the position given in Table 5-3. The RMS variation in the position errors for each emplaced IVS item was under 3 cm. The depth error statistics for the IVS items are listed in Table 5-5 and shown in the right panel of Figure 5-12. The RMS variation in the depth errors for each emplaced IVS item was under 1.5 cm.

Table 5-5 – 5x5 Array Summary of Position and Depth Error Statistics for all items emplaced in the IVS.

Item	Easting Position Error (cm)				Northing Position Error (cm)				Depth Error (cm)			
	Min	Max	Mean	RMS	Min	Max	Mean	RMS	Min	Max	Mean	RMS
Shotput	-2.50	3.90	0.40	1.60	-4.20	3.50	-0.30	2.00	-8.50	-6.40	-7.30	0.80
37mmP	-7.10	-0.40	-3.20	2.10	-2.50	2.80	-0.10	1.40	-1.30	1.80	-0.10	1.10
75mmP	-4.40	1.70	-1.90	1.80	-1.90	2.00	-0.20	1.30	-2.40	1.00	0.10	1.20
ISO2	-2.30	2.30	-0.30	1.40	-1.60	1.20	-0.20	1.00	1.10	1.70	1.40	0.20

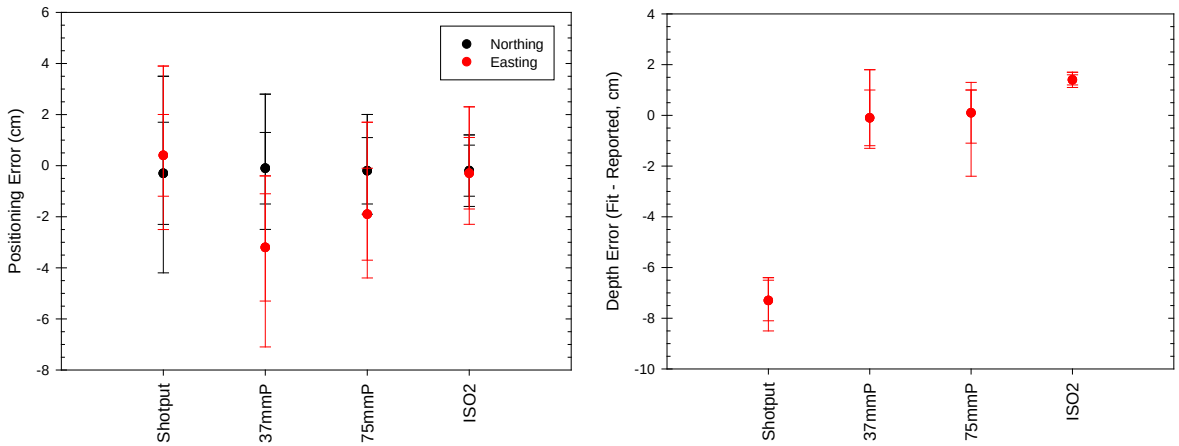

Figure 5-12 – 5x5 Array Position error statistics for the four items emplaced in the IVS (left panel). Easting data are in black and Northing data are in red. Depth error statistics for the same items (right panel).

5.4.3.2. TEMTADS MP 2x2 System – Cued Surveys

For the MP system, the IVS results are presented separately for the cued data collection and for the dynamic data collection, as the deployment mode and data acquisition parameters were different for each case.

The results for the eleven cued mode IVS measurements are given in Table 5-6 and shown in Figure 5-13. The RMS variation in the magnetic polarizability amplitudes at 0.089 ms were less than 4% of the mean amplitude for all IVS items and for all three magnetic polarizabilities. The results were qualitatively the same as those seen for the 5x5 Array. A direct comparison is not attempted due to different receiver configurations and associated decay times evaluated. The aggregate depth error statistics for the IVS items are listed in Table 5-7 and shown in Figure 5-14. The RMS variation in the depth errors for each emplaced IVS item was under 2 cm.

Table 5-6 – MP System, Cued Mode, Summary of the Amplitude Variations at 0.089 ms in the Derived Response Coefficients for All Items Emplaced in the IVS.

Item	β_1 Amplitude (m^3)				β_2 Amplitude (m^3)				β_3 Amplitude (m^3)			
	Min	Max	Mean	RMS	Min	Max	Mean	RMS	Min	Max	Mean	RMS
Shotput	0.41	0.44	0.42	0.01	0.36	0.39	0.37	0.01	0.30	0.32	0.30	0.01
37mmP	0.16	0.18	0.17	0.01	0.13	0.14	0.14	0.00	0.12	0.14	0.13	0.00
75mmP	1.51	1.65	1.56	0.04	1.45	1.58	1.50	0.04	1.42	1.52	1.48	0.03
ISO2	0.48	0.52	0.49	0.01	0.24	0.26	0.25	0.00	0.24	0.25	0.25	0.00

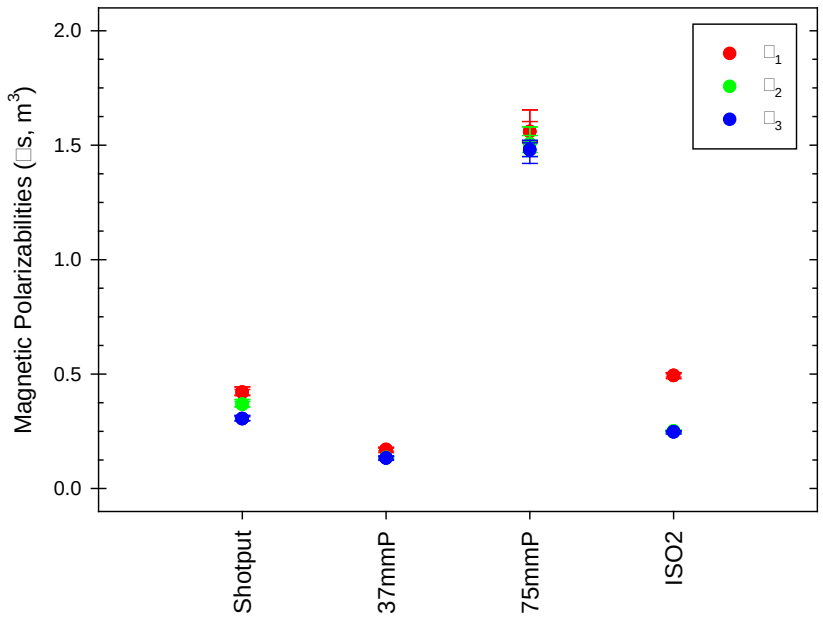

Figure 5-13 – MP System, Cued Mode, derived response coefficients amplitude variations at 0.089 ms in the derived response coefficients for all items emplaced in the IVS. β_1 is in red; β_2 is in green; and β_3 is in blue.

Table 5-7 – MP System, Cued Mode, Summary of Depth Error Statistics for all items emplaced in the IVS.

Item	Depth Error (cm)			
	Min	Max	Mean	RMS
Shotput	-8.70	-4.20	-5.30	1.50
37mmP	0.80	4.20	2.90	1.00
75mmP	-6.10	-2.60	-3.80	1.20
ISO2	-3.80	1.20	-0.80	1.50

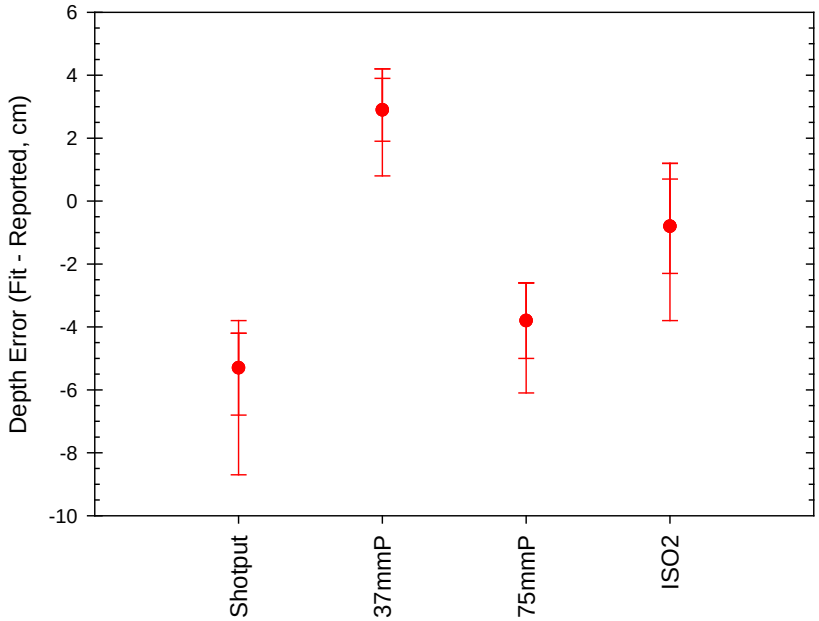

Figure 5-14 – MP System, Cued Mode, Depth Error Statistics for all Items Emplaced in the IVS.

5.4.3.3. TEMTADS MP 2x2 System – Dynamic Surveys

The results for the survey mode IVS measurements are given in Table 5-8 and shown in Figure 5-15. The RMS (1σ) values for the magnetic polarizability amplitudes at 0.082 ms were unsurprising significantly higher than those for the cued measurements. The variation for the shotput was the worst, at 30% for all three magnetic polarizability components. The remaining components were typically in the range of 10 – 20% variation. The results are qualitatively the same as those seen for the cued systems. The aggregate depth error statistics for the IVS items are listed in Table 5-9 and shown in Figure 5-16. The RMS variation in the depth errors for each emplaced IVS item were all under 2.5 cm. It is important to note that only four measurements of the IVS form these aggregate values, a very small population.

Table 5-8 – MP System, Survey Mode, Summary of the Amplitude Variations at 0.082 ms in the Derived Response Coefficients for All Items Emplaced in the IVS.

Item	β_1 Amplitude (m^3)				β_2 Amplitude (m^3)				β_3 Amplitude (m^3)			
	Min	Max	Mean	RMS	Min	Max	Mean	RMS	Min	Max	Mean	RMS
Shotput	0.38	0.75	0.52	0.16	0.34	0.61	0.43	0.12	0.29	0.53	0.364	0.11
37mmP	0.13	0.20	0.16	0.03	0.13	0.15	0.14	0.01	0.12	0.15	0.132	0.01
75mmP	1.48	1.93	1.66	0.19	1.40	1.86	1.55	0.21	0.80	1.64	1.313	0.37
ISO2	0.43	0.62	0.51	0.09	0.25	0.36	0.29	0.05	0.24	0.32	0.27	0.04

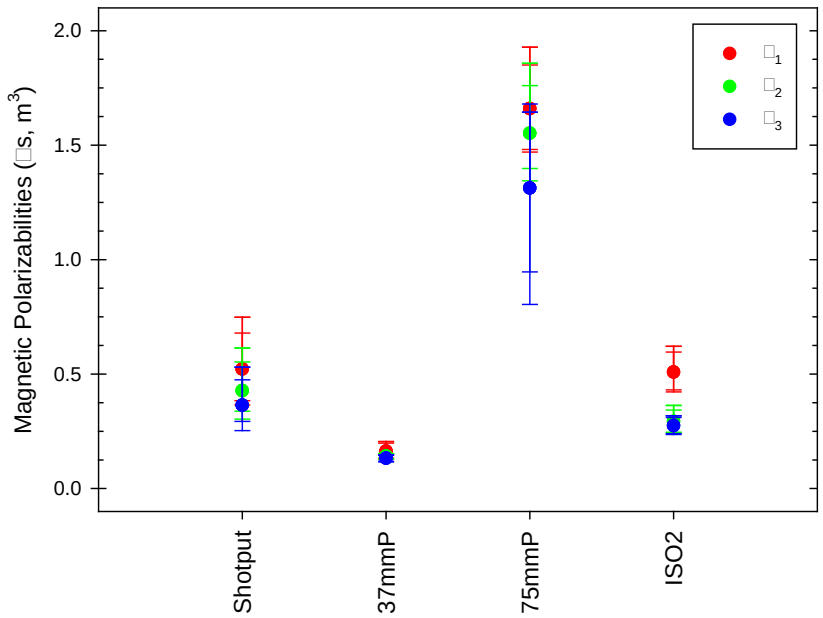

Figure 5-15 – MP System, Survey Mode, derived response coefficients amplitude variations at 0.082 ms in the derived response coefficients for all items emplaced in the IVS. β_1 is in red; β_2 is in green; and β_3 is in blue.

Table 5-9 – MP System, Survey Mode, Summary of Position and Depth Error Statistics for all items emplaced in the IVS.

Item	Easting Position Error (cm)				Northing Position Error (cm)				Depth Error (cm)			
	Min	Max	Mean	RMS	Min	Max	Mean	RMS	Min	Max	Mean	RMS
Shotput	-1.00	3.50	1.40	2.10	-6.10	7.80	0.60	6.00	-6.40	-0.80	-4.20	2.40
37mmP	-4.90	-0.10	-3.20	2.20	-7.10	7.20	1.20	6.10	2.50	3.90	3.20	0.70
75mmP	-8.50	-3.90	-6.70	1.90	-4.30	6.70	1.30	4.60	-5.50	-2.40	-3.70	1.40
ISO2	5.70	11.40	7.70	2.70	-7.10	10.90	1.20	7.60	-1.70	0.80	-0.60	1.10

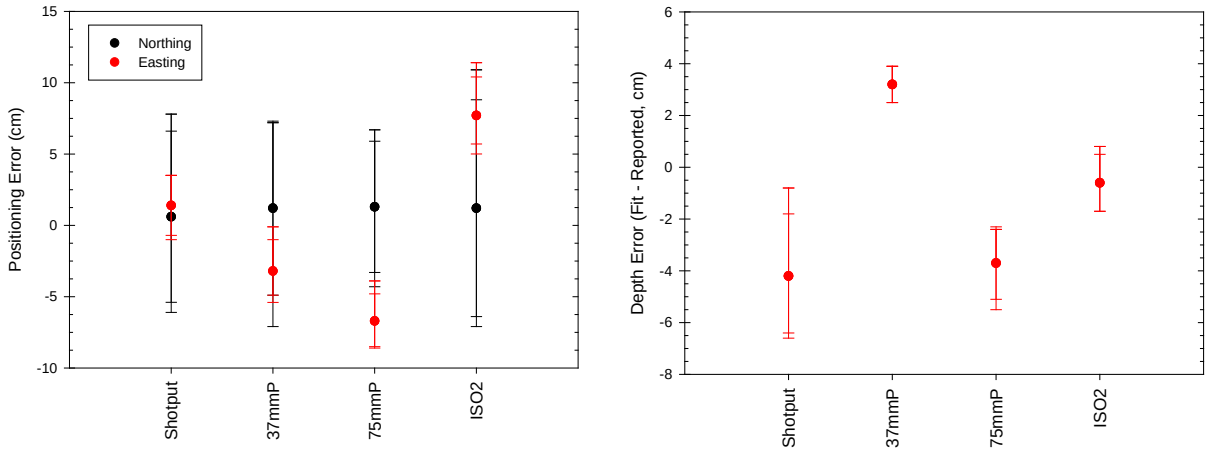

Figure 5-16 – MP System, Survey Mode, and Positioning and Depth Error Statistics for Items Emplaced in the IVS.

5.4.4 Additional Calibration Activities

There was a test pit provided onsite, near the IVS, which was used to further populate our reference library of TOI fit parameters. These data will provide additional training data to the classification demonstrators. Please refer to the ESTCP Live Site Demonstrations Plan for further details.

After a review of our signature libraries, the 3-in Stokes mortar, inclined at a 45º angle was the only signature missing from our library for cued data collection parameters. For the MP System operating in dynamic mode, all of the signatures indicated in the Program Office Demonstration Plan [1] required measurement. We measured four items: the 37mm projectile, the ISO2, the 3-in Stokes mortar, and the 105mm HEAT projectile. The 3-in Stokes mortar was made available as a surrogate for the 75mm projectile. All of the available inert 75mm projectiles had been buried as seeds. An inert 75mm projectile was brought to the site at the end of the demonstration, but too late to be measured. Measurements were made in the required orientations: vertical - nose up, vertical - nose down, horizontal, and at a 45º incline. The vertical – nose up and vertical – nose down orientations for the ISO2 are the same and only one measurement was made.

5.5 DATA COLLECTION PROCEDURES

5.5.1 Scale of Demonstration

NRL conducted a series of cued data collections within the 9.4-acre demonstration site at the former Spencer Artillery Range, TN in May 2012. For the Open Area, 1,168 anomalies were the subject of cued 5x5 Array data collection. For the Wooded Area, 714 anomalies were investigated in a cued data collection using the MP System. For the Dynamic Area, a dynamic survey was conducted with the MP System, anomalies selected from the survey data, and a cued survey conducted on the union of the dynamic survey anomaly list and EM61-MK2 anomaly list

held by the Program Office, for 389 total anomalies. Performance of the system response was monitored on a twice-daily basis using the onsite IVS. The data segment (chip) for each anomaly was analyzed, and dipole model fit parameters extracted. These results were then provided to the ESTCP Program Office along with the archival data.

5.5.2 Sample Density

The EMI data spacing for the TEMTADS is fixed at 40 cm in both along- and cross-track directions by the array design.

5.5.3 Quality Checks

Preventative maintenance inspections were conducted at least once a day by all team members. Any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios are available in the system spares inventory which will be on site. Status on any break-downs / failures which would have resulted in long-term delays in operations would have been immediately reported to the ESTCP Program Office.

For the 5x5 Array, the GPS data QC procedures and checks were as follows. The status of the RTK GPS system was visually determined by the operator prior to starting the data collection cycle, assuring that the position and orientation information are valid, typical Fix Quality (FQ) 3, during the collection period. A Fix Quality (FQ) value of 3 (RTK Fixed) is the best accuracy (typically 3-5 cm or better). A FQ value of 2 (RTK Float) indicates that the highest level of RTK has not be reached yet and location accuracy can be degraded to as poor as ~1 m. FQs 1 & 4 correspond to the Autonomous and DGPS operational modes, respectively. Data collected under FQ 3 and FQ 2 (at the discretion of the data analyst) were retained.

For the 5x5 Array, two data quality checks were performed on the EMI data. After background subtraction, monostatic contour plots were made of the signal at 0.042 ms from the 25 transmit/receive pairs. The plots were visually inspected to verify that there was a well-defined, well-centered anomaly without any extraneous signals or dropouts. QC on the transmit/receive cross terms was based on the dipole inversion results. Our experience has been that data glitches show up as reduced dipole fit coherence.

The vehicle operator has access to a numerical version of the monostatic contour plot, as shown in Figure 5-17, to allow for on-the-fly data QC. An example monostatic contour plot for a high SNR anomaly centered under the array is shown in Figure 5-17a. For any anomaly where none of the central nine monostatic amplitudes (at 42 μs) exceeds the 5 mV/Amp threshold, as shown in Figure 5-17b, the vehicle operator would reposition the array approximately 20 cm and acquired a second data set. The operator display is not current normalized, so the threshold is 0.030, as expressed in mV.

Any data set deemed unsatisfactory by the data analyst was flagged and not processed further. The anomaly corresponding to the flagged data was logged for future re-acquisition. Data which met these standards was of the quality typical of the TEMTADS system.

The data QC procedures for the TEMTADS MP 2x2 Cart in cued mode were very similar to those described above and are not repeated here. Further details are available in Reference 10.

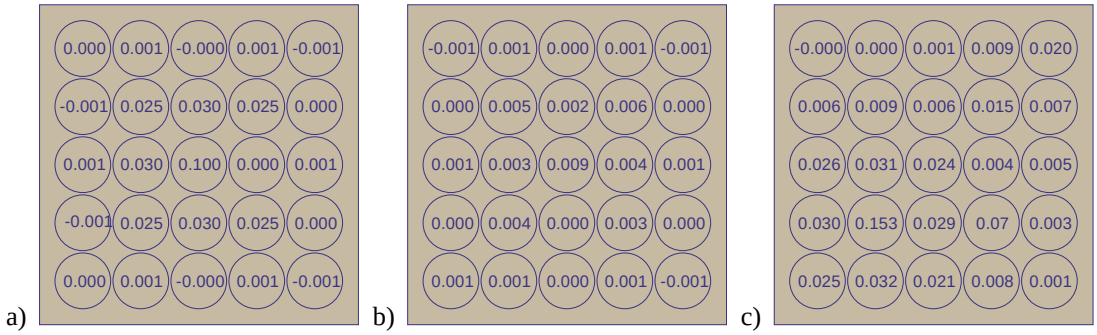

Figure 5-17 – TEMTADS Operator Monostatic Contour Plot Display: a) A single anomaly well centered under the array, b) a low SNR anomaly centered under the array, c) two anomalies, one strong and one weak, with neither directly under the array center. The strong anomaly is sufficiently illuminated to resolve. The weak anomaly is at the array edge and may require reacquisition. These values are in mV (not mV/A) and are not current-normalized.

For the MP system operating in dynamic mode, the data QC process is similar again, but applied to lines of data rather than single data points. The TEM response for data points associated with both background locations and over targets were inspected for reasonable values and variation. A TEM data profile along survey line is shown in Figure 5-18. The recorded transmitter current for each transmit period was inspected to insure a good transmit cycle. A transmitter misfire typically does not reach the average peak value and would have a non-standard waveform. An example is shown in Figure 5-19, where transmitter Tx2 misfired (see Figure 5-6 for sensor numbering). GPS FQ values were evaluated. If the GPS receiver loses its FQ3 RTK solution for short periods, the positions are interpolated over. For longer periods, the data analyst called for recollection.

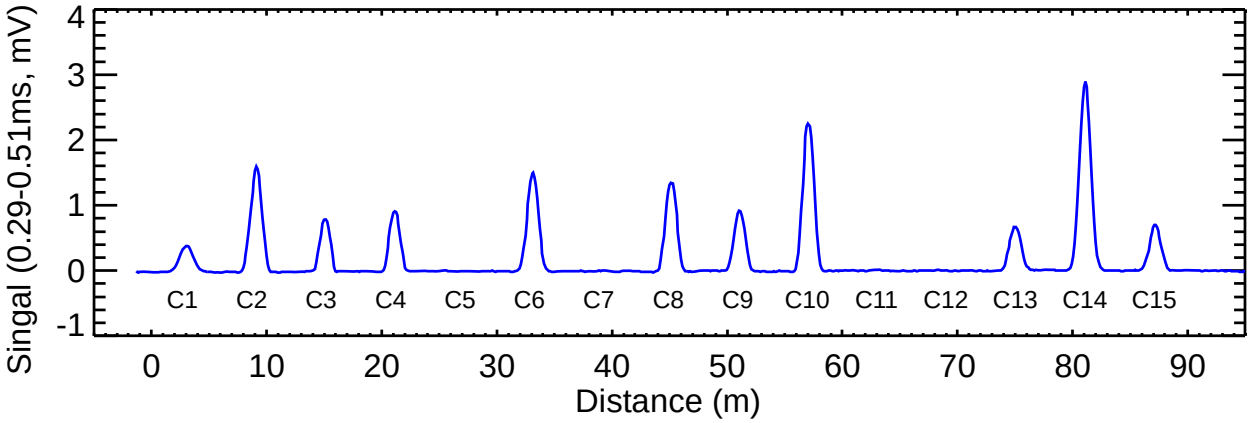

Figure 5-18 – TEMTADS MP 2x2 Cart TEM data profile along a survey line over line C in the NRL Blossom Point Test Field. The Signal is the sum of the monostatic TEM decays for all four sensors summed over the time bins centered from 0.29 to 0.51 msec.

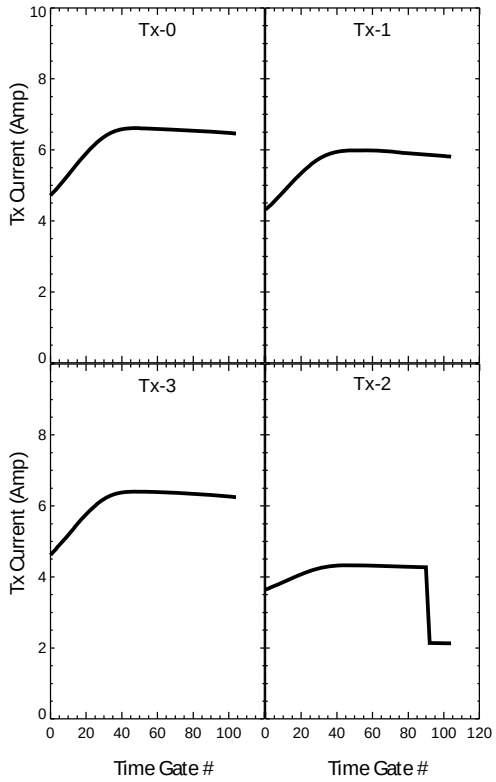

Figure 5-19 – TEMTADS MP 2x2 Cart transmit current waveforms for a bad transmit cycle. In this case, transmitter Tx2 misfired.

5.5.4 Data Handling

Data were stored electronically as collected on the data acquisition computer hard drives. Approximately every survey hour, the collected data were copied onto removable media and transferred to the data analyst for QC/analysis. The data were moved onto the data analyst's computer and the media was recycled. Raw data and analysis results were backed up from the data analyst's computer to external hard disks daily. These results were archived on an internal file server at NRL or SAIC at the end of the survey. Examples of the 5x5 Array file formats are provided in Appendix C. Examples of the MP system file formats, which are very similar, are available in Reference 10. All field notes / activity logs were written in ink and stored in archival field notebooks. These notebooks were archived at NRL or SAIC. Relevant sections are reproduced in reports such as this document. Dr. Tom Bell is the POC for obtaining data and other information. His contact information is provided in Appendix B of this report.

5.6 VALIDATION

At the conclusion of data collection activities, all anomalies on the master anomaly list assembled by the Program Office will be excavated. Each item encountered will be identified, photographed, its depth measured, its location determined using cm-level GPS, and the item removed if possible. This ground truth information, once released, will be used to validate the objectives listed in Section 3.0

6.0 DATA ANALYSIS PLAN

The data analysis plan for the MP System is presented in this Section. The data analysis plan for the 5x5 Array is very similar and only varies in the number and configuration of transmitter and receiver loops. Further details on the 5x5 Array can be found in Reference 11.

6.1 PREPROCESSING

The MP System has four sensor elements, each comprised of a transmitter coil and a tri-axial receiver cube. For each transmit pulse, the responses at all of the receivers are recorded. This results in 48 possible transmitter / receiver combinations in the data set (4 transmitters x 4 receiver cubes x 3 receiver axes). Although the data acquisition system records the signal over 122 logarithmically-spaced time gates, the measured responses over the first 17 gates included distortions due to transmitter ringing and related artifacts and are discarded. We further subtract 0.028 ms from the nominal gate times to account for time delay due to effects of the receive coil and electronics [21]. The delay was determined empirically by comparing measured responses for test spheres with theory. This leaves 105 gates spaced logarithmically between 0.089 ms and 25.35 ms. In preprocessing, the recorded signals are normalized by the peak transmitter current to account for any variation in the transmitter output. On average, the peak transmitter current is approximately 7.5 Amps.

The background response is subtracted from each target measurement using data collected at a nearby target-free background location. The background measurements are reviewed for variability and to identify outliers, which may correspond to measurements over targets. In previous testing at our Blossom Point test field and during other demonstrations, significant background variability was not observed. It has been possible to use blank ground measurements from 100 meters away for background subtraction. Changes in moisture content and outside temperature have been shown to cause variation in the backgrounds, necessitating care when collecting data after weather events such as rain.

Data preprocessing for the 5x5 Array is very similar to that for the MP System. For the 5x5 Array, there are 625 possible transmitter /receiver combinations in the data set (25 transmitters x 25 receivers x 1 receiver axis). The first seven time gates are excluded, leaving 115 time gates ranging from 0.042 to 25.25 ms. On average, the peak transmitter current is approximately 6 Amps.

For the MP system dynamic survey of the Dynamic Area, data preprocessing is essentially unchanged from the cued mode method described above. Data are collected in survey lines rather than individual points and platform position and orientation information are available.

6.2 TARGET SELECTION FOR DETECTION

Anomaly detection was only involved in the MP system dynamic survey of the Dynamic Area. An anomaly detection procedure similar to the one described in Reference 3 was used. As this was the first outing of the MP system in dynamic mode, a data analyst made each anomaly selection rather than an automated peak picker routine. The anomaly detection criteria were unchanged. A preliminary detection threshold was selected based on physical models of the systems response to the expected TOI, as described in Section 6.2.1. The site-specific background signal levels were considered as well. Anomalies were picked from mapped data. The mapped data from the Dynamic area are shown in Figure 6-1. The data presented are monostatic response from each sensor at the tenth usable time gate, 1.024 ms.

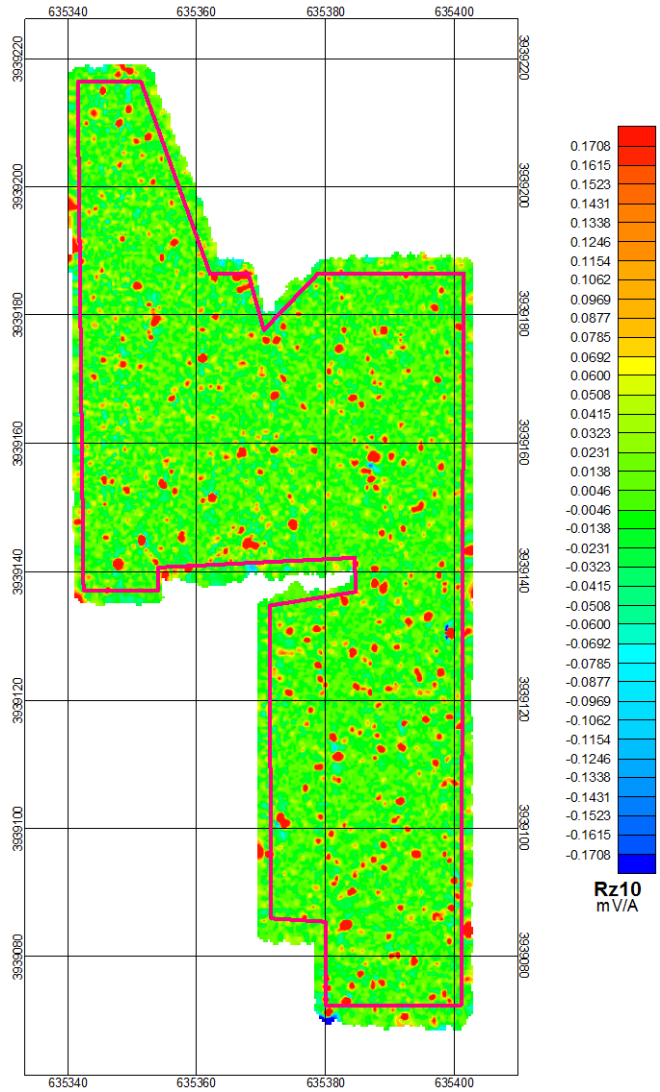

Figure 6-1 – Located and leveled dynamic data (1.024 ms) from the MP System for the Dynamic Area at the former Spencer Artillery Range, TN.

6.2.1 Detection Threshold Selection

The ESTCP Demonstration Plan for the former Spencer Artillery Range demonstration [1] set an objective of detecting 37mm projectiles to a burial depth of 34 cm. To establish a detection threshold for this objective with the MP system operating in dynamic survey mode, a series of forward model cases were run using the polarizabilities of known 37mm projectiles and actual, measured survey track positions from our test field. In dynamic survey mode, the earliest usable time gates are in the 0.1 to 0.2 msec range. Therefore, the first time gate considered in the forward model cases was 0.135 msec. The weakest responses are 37mm projectiles oriented horizontally.

A forward model was run with a fixed object depth of 34 cm, but over a range of object – survey tracks separations and a range of object azimuth orientations. The results indicated that the expected peak signals for the 37mm projectile are found within the range of 1.6 to 2.1 mV/A at 0.135 ms. Based on these modeling results, a pre-demonstration, conservative detection level of 1.0 mV/A was selected for the TEMTADS MP system dynamic survey.

Figure 6-2 contours the mono-static signal responses for nine of these modeled cases. The nine cases presented placed the 37mm projectile at the three locations indicated in the plot with X's. At each location, the horizontal projectile is oriented along track, across track, and at 45 degrees relative to the track. The cart course-over-ground paths are plotted with small, gray symbols. The contour levels plotted are 0.2, 0.5, 1.0, and 2.0 mV. The two largest-amplitude contour levels are colored red. Based on these modeling results, a preliminary detection level of 1.0 mV/A was selected for the TEMTADS MP system dynamic survey at the former Spencer Artillery Range.

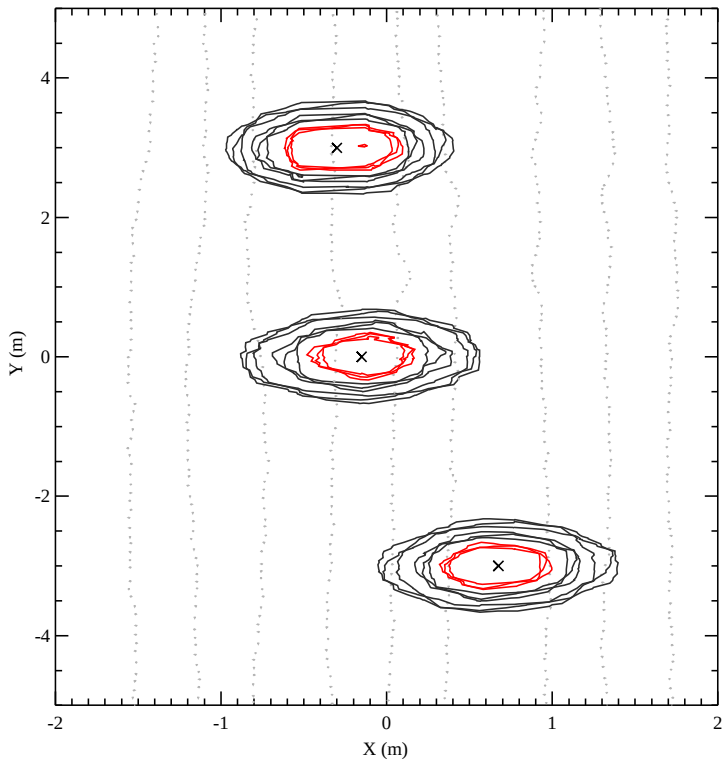

Figure 6-2 – TEMTADS MP System mono-static signal response contour plot for nine forward model cases. The three locations used in the models for the 37mm projectile location are indicated by X's. At each location, the projectile is oriented horizontally and along track, across track, and at 45 degrees relative to the track. The cart course-over-ground path is plotted with small, gray symbols. The contour levels plotted are 0.2, 0.5, 1.0, and 2.0 mV. The two largest-amplitude contour levels are colored red.

After the data were collected and reviewed, it was determined that the last time gate (of 10 used for analysis) was a better choice for target picking. The response from small, thin-walled items have had a chance to decay away while the response from a 37mm projectile still remained sufficiently above background for target picking. The same model used above was used to determine the proper threshold of the 10th time gate and was found to be 0.18 mV/A. Therefore, we decided to use the 10th time gate for initial selection and the 1st time gate with the corresponding model prediction of in the range of 1.6 to 2.1 mV/A threshold to confirm our picks. This threshold is within the range stipulated in the original plan. If a peak passed the threshold at both time gates, it was added to the target list.

6.3 PARAMETER ESTIMATION

The raw signature data from TEMTADS sensors reflect details of the sensor/target geometry as well as inherent EMI response characteristics of the targets themselves. In order to separate out the intrinsic target response properties from sensor/target geometry effects, we invert the signature data to estimate principal axis magnetic polarizabilities for the targets. The TEMTADS data are inverted using the standard induced dipole response model wherein the effect of eddy currents set up in the target by the primary field is represented by a set of three orthogonal magnetic dipoles at the target location [22]. The measured signal is a linear function of the induced dipole moment **m**, which can be expressed in terms of a time dependent polarizability tensor **B** as

$$\mathbf{m} = \mathbf{UBU}^{T} \cdot \mathbf{H}_0$$

where **U** is the transformation matrix between the physical coordinate directions and the principal axes of the target and $\mathbf{H}_0$ is the primary field strength at the target. The eigenvalues $\beta_i(t)$ of the polarizability tensor are the principal axis polarizabilities.

Given a set of measurements of the target response with varying geometries or "look angles" at the target, the data can be inverted to determine the local (X,Y,Z) location of the target, the orientation of its principal axes (ϕ,θ,ψ), and the principal axis polarizabilities (β_1,β_2,β_3). The basic idea is to search out the set of nine parameters ($X,Y,Z,\phi,\theta,\psi,\beta_1,\beta_2,\beta_3$) that minimizes the difference between the measured responses and those calculated using the dipole response model. Since the system currently does not know or record the location or orientation of the cart, target location and orientation are known well locally but not well geo-referenced.

For TEMTADS data, inversion is accomplished by a two-stage method. In the first stage, the target's (X,Y,Z) dipole location is solved for non-linearly. At each iteration within this inversion, the nine element polarizability tensor (**B**) is solved linearly. We require that this tensor be symmetric; therefore, only six elements are unique. Initial guesses for X and Y are determined by a signal-weighted mean. The routine normally loops over a number of initial guesses in Z, keeping the result giving the best fit as measured by the chi-squared value. The non-linear inversion is done simultaneously over all time gates, such that the dipole (X,Y,Z)

location applies to all decay times. At each time gate, the eigenvalues and angles are extracted from the polarizability tensor.

In the second stage, six parameters are used: the three spatial parameters (X,Y,Z) and three angles representing the yaw, pitch, and roll of the target (Euler angles ϕ,θ,ψ). Here the eigenvalues of the polarizability tensor are solved for linearly within the 6-parameter non-linear inversion. In this second stage both the target location and its orientation are required to remain constant over all time gates. The value of the best fit X,Y,Z from the first stage, and the median value of the first-stage angles are used as an initial guess for this stage. Additional loops over depth and angles are included to better ensure finding the global minimum.

Figure 6-3 shows an example of the principal axis polarizabilities determined from TEMTADS array data. The target, a mortar fragment, is a slightly bent plate about 0.5 cm thick, 25 cm long, and 15 cm wide. The red curve is the polarizability when the primary field is normal to the surface of the plate, while the green and blue curves correspond to cases where the primary field is aligned along each of the edges.

Not every target on the target list exhibited a strong enough TEM response to support extraction of target polarizabilities. All of the data were run through the inversion routines, and the results manually screened to identify those targets that could not be reliably parameterized. Several criteria were used: signal strength relative to background, dipole fit error (difference between data and model fit to data), and the visual appearance of the polarizability curves.

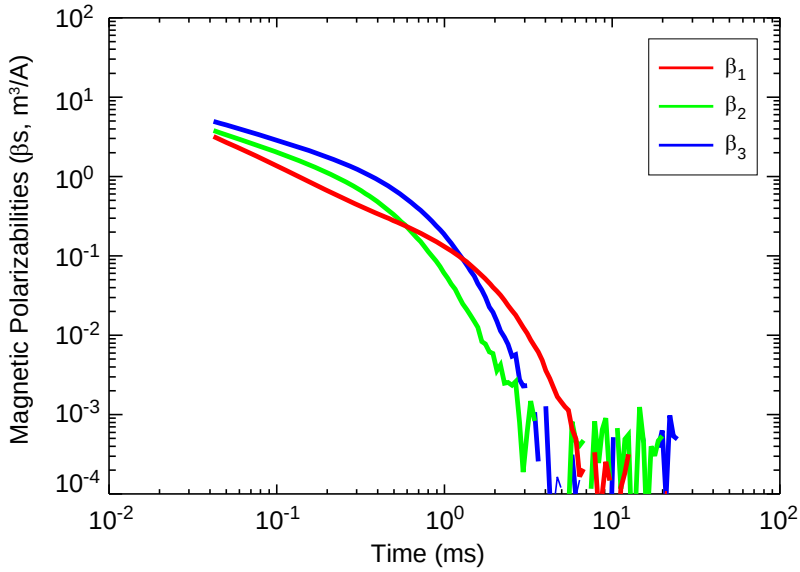

Figure 6-3 – Principal axis polarizabilities for a 0.5 cm thick by 25 cm long by 15 cm wide mortar fragment.

6.4 DATA PRODUCT SPECIFICATIONS

See Appendix C for the detailed data product specifications.

7.0 PERFORMANCE OBJECTIVES

The performance objectives for this demonstration are summarized in Table 3-1 and are repeated here in Table 7-1. The results for each criterion are subsequently discussed in the following sections.

Table 7-1 – Performance Results for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria	Success? (Yes/No)
Dynamic Survey Objectives				
Along-line measurement spacing	Point-to-point spacing from data set	Mapped survey data	98% < 25 cm along-line spacing	Yes
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	Calculated using UXProcess Footprint Coverage QC Tool and a sensor footprint of 80cm	Yes
Detection of all targets of interest (TOI)	Percent detected of seeded items	Location of seeded items Anomaly List	100% of seeded items detected within a 60 cm halo	No
All Surveys Objectives				
Instrument Verification Strip (IVS) Results	Fit results from each emplaced item Measured locations of emplaced items	Daily IVS data	Down-track location ±10 cm Polarizabilities: βs ±10%	*Cued*: Yes *Dynamic*: No
Cued interrogation of anomalies	Instrument position	Cued survey data	100% of anomalies where the center of the instrument is positioned within a given distance of the actual target location	Yes
			TEMTADS 5x5: 60 cm	
			TEMTADS 2x2: 40 cm	

7.1 ALONG-LINE MEASUREMENT SPACING

The value of the collected dynamic data depends on the extent of coverage of the site that it represents. Gaps in coverage impede or prevent analysis of the data. This objective concerns the ability to collect dynamic data with acceptable along-line data density.

7.1.1 Metric

The metric for this objective was the percentage of data points within acceptable along-line spacing. Provisions for exceptions based on topology / vegetation interferences were made, but not required.

7.1.2 Data Requirements

A mapped data file was used to judge the success of this objective.

7.1.3 Success Criteria

This objective was considered met if at least 98% of the mapped data points were within 25 cm of the neighboring data points along the survey line. The acceptable along-line spacing was increased from the 15 cm specified for the EM61-MK2 in Reference 1 to 25 cm due to the data rate of the MP system.

7.1.4 Results

The average along-track separation for the Dynamic Area dynamic survey was 13.8 cm. The percentage of mapped data points within 25 cm of the neighboring data points was 99.8%.

7.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The value of collected survey data depends on the extent of coverage of the site. This objective concerns the ability to completely survey the site and obtain sufficient data coverage. Provisions for exceptions based on topology / vegetation interferences were made, but not required.

7.2.1 Metric

The metric for this objective was the footprint coverage as measured by the UXProcess Footprint Coverage QC tool.

7.2.2 Data Requirements

A mapped data file was used to judge the success of this objective.

7.2.3 Success Criteria

This objective was considered met if the survey achieved at least 85% coverage at 0.5-m line spacing and 98% at 0.75-m line spacing, as determined using the UX-Process Footprint Coverage QC tool.

7.2.4 Results

The demonstration was successful for this objective. The UX-Process Footprint Coverage QC tool report indicates 100% coverage of the site with a sensor footprint of 80cm. See Figure 7-1 for the tools output.

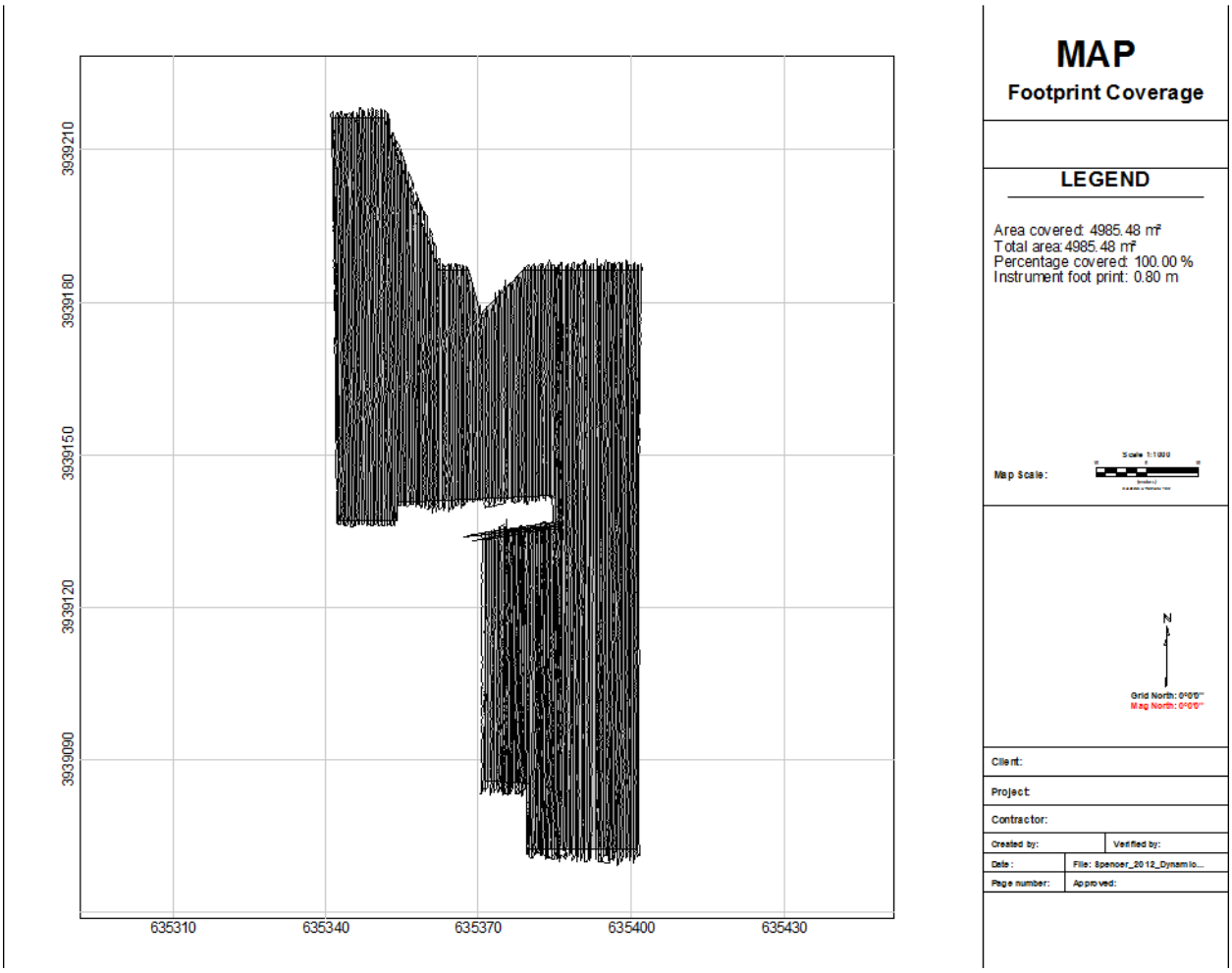

Figure 7-1 – UX-Process Footprint Coverage QC tool output map for the MP system dynamic survey of the Dynamic Area.

7.3 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST (TOI)

Quality data should lead to a high probability of detecting the TOI at the site.

7.3.1 Metric

The metric for this objective was the percentage of seed items that were detected using the specified anomaly selection threshold.

7.3.2 Data Requirements

Each demonstrator prepared an anomaly list. USACoE personnel evaluated the detection probability of the seeded items as part of their data Quality Assurance (QA) review.

7.3.3 Success Criteria

The objective was considered to be met if 100% of the seeded items were detected within a halo of 60 cm.

7.3.4 Results

At the completion of the dynamic survey of the Dynamic Area, a target list was produced using the criteria outlined in Section 6.2. As this was the first live-site demonstration of this sensor in this mode of operation, a data analyst manually evaluated each target selection. The resulting target list was submitted to the Program Office for evaluation by the USACoE, Huntsville. One seed item was missed by the data analyst even though the data for that location met the selection criteria. A root-cause-analysis determined the threshold exceedance for the late time gate was not well-formed and discarded by the data analyst. See Figure 7-2. Additionally, the centroids of the peaks at the early and late time gates did not line up well. The data coverage over the seed was good, as shown in Figure 7-3. With the aggressive schedule required for this demonstration, fatigue and time pressure on the data analyst played an additional role.

In future demonstrations, an automated version of the target picking process will be used and will prevent this type of error.

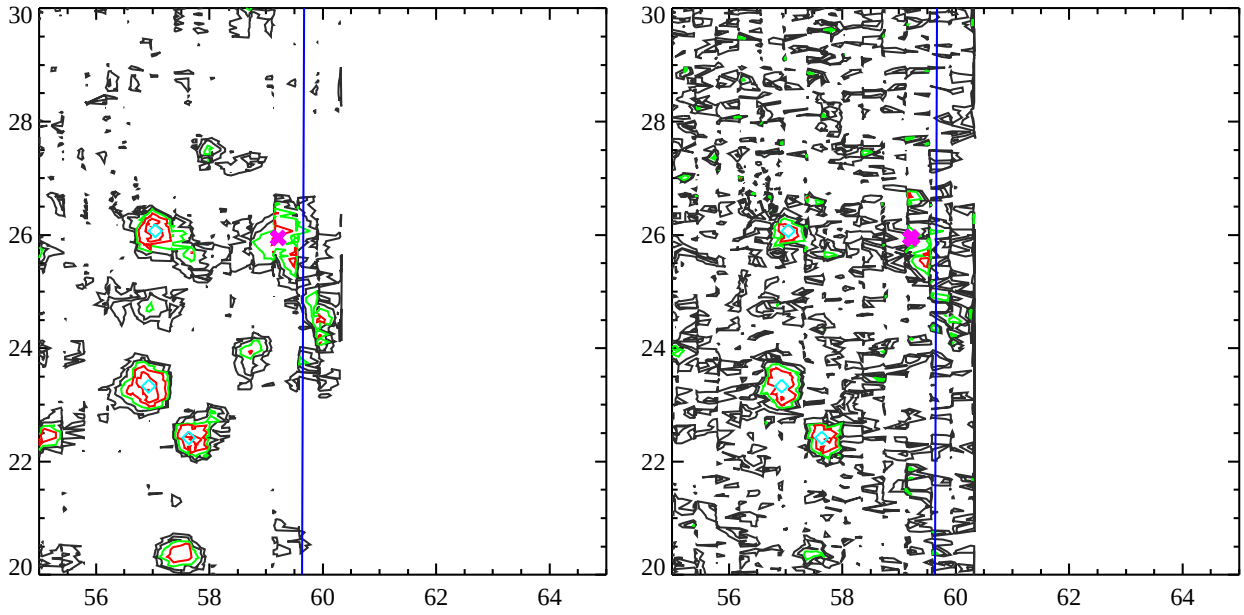

Figure 7-2 – Data contour plots for the early selection time gate (0.137 ms, left) and the late selection time gate (1.024 ms, right). Position is given in local coordinates (meters).

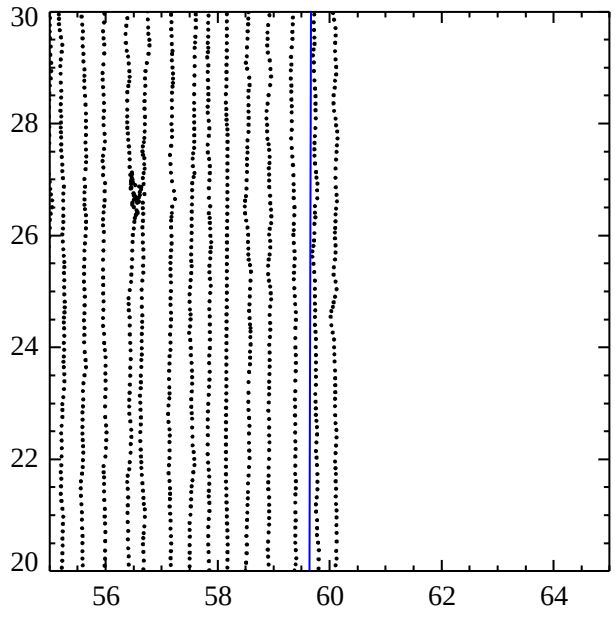

Figure 7-3 – Data coverage over the missed seed item. Position is given in local coordinates (meters).

7.4 OBJECTIVE: INSTRUMENT VERIFICATION STRIP (IVS) RESULTS

This objective demonstrates that the sensor system was in good working order and collecting physically valid data each day. The Instrument Verification Strip (IVS) was surveyed twice daily. The amplitudes of the derived response coefficients for each emplaced item were compared to the running average of the demonstration for reproducibility. The extracted fit locations of each item were compared to the reported ground truth and the running average of the demonstration.

7.4.1 Metric

The reproducibility of the measured responses of the sensor system to the emplaced items and of the extracted locations of the emplaced items defines this metric.

7.4.2 Data Requirements

The tabulated fit parameters for the data corresponding to each emplaced item in terms of derived response coefficients, location, and depth.

7.4.3 Success Criteria

The objective was considered met if the RMS amplitude variation of the derived response coefficients was less than 10% and the down-track fit location of the anomaly was within 10 cm of the corresponding seeded item's stated location.

7.4.4 Results

As discussed in Section 5.4.3, the RMS amplitude variations for the magnetic polarizabilities for cued surveys all fell below the 10% cutoff. For the MP system dynamic surveys, RMS variation in the polarizabilities was typically 10 – 20% with the worse case being for the shotput at 30%. As discussed in Section 5.4.3, this particular shotput does not appear to have a sphere-like response which affects both the polarizabilities and the fitted depth. It should be noted that the dynamic MP system data collection was only two days long, resulting in only four measurements of the IVS and limiting the value of the statistical results. Referring to Table 5-5 and Table 5-9, it is clear that the down-track fit locations of each item were well within 5 cm of the stated location, and so the second criterion was also met.

7.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

To collect EMI data of the highest quality for UXO/clutter classification, the anomaly must be illuminated along its three principle axes. To insure this, the data collection pattern (in this case the TEMTADS array) must be positioned directly over the center of the anomaly.

7.5.1 Metric

The metric for this objective was the percentage of anomalies where the center of the instrument was within the acceptable distance range from the actual target location.

7.5.2 Data Requirements

Demonstrators provided the ESTCP Program Office a weekly list of the location of the center of their instrument for each cued anomaly interrogated in the preceding week. The USACoE, Huntsville reviewed the offsets for the QC seeds and provide feedback to the demonstrator if their instrument was not within the acceptable distance. In the case of a failure, the demonstrator would have been required to reacquire data for those anomalies interrogated during the effected period and perform a root cause analysis for each failure.

7.5.3 Success Criteria

The objective was considered met for the 5x5 Array if the center of the instrument was positioned within 60 cm of the actual anomaly location for 100% of the cued anomalies. For the MP system, no global positioning is available. For the MP system, the criterion was that the fit location of the anomaly was within 40cm of the array center.

7.5.4 Results

After the 5x5 Array survey was complete, a list of the recorded array center for each anomaly was forwarded to the Program Office and USACoE. All recorded locations corresponding to seeds were found to be within the 60cm requirement. For the MP System cued measurements, the position is not recorded. As such, the metric of requiring that the inverted location of each anomaly not fall outside the sensor footprint (40 cm from the array center) was used. If a fit location indicated that the anomaly was outside the sensor footprint, a new data set was required with a refined position until the criterion was met or the indicated position was determined to be unreachable, such as located under a tree.

8.0 COST ASSESSMENT

8.1 COST MODEL

The cost elements tracked for this demonstration are detailed in Table 8-1 and Table 8-2. The provided cost elements are based on a model recently developed for cost estimation for the MP system at Camp Beale in 2011 [10]. The model assumes a two-person field crew and one data analyst. Table 8-1 contains the cost model for the 5x5 Array. Table 8-2 contains the cost model for the MP system. While neither system is currently commercially available, an estimated daily rental rate for the MP system is provided for comparison to other technologies. The rental rate is based, in part, on the costs of items purchased in prototype quantities (single units) and would presumably decrease significantly if the items were procured at production quantity levels.

8.2 COST DRIVERS

Two factors were expected to be strong drivers of cost for this technology as demonstrated. The first is the number of anomalies which can be surveyed per day. Higher productivity in data collection equates to more anomalies investigated for a given period of time in the field. The time required for analyzing individual anomalies can be significantly higher than for other, more traditional methods and could become a cost driver due to the time involvement. The thoughtful use of available automation techniques for individual anomaly analysis with operator QC support can moderate this effect.

8.3 COST BENEFIT

The main benefit to using a UXO classification process is cost-related. The ability to reduce the number of non-hazardous items that have to be dug or have to be dug as presumptively-hazardous items directly reduces the cost of a remediation effort. The additional information for anomaly classification provided by these sensor systems provides additional information for the purposes of anomaly classification. If there is buy-in from the stakeholders to use these techniques, this information can be used to reduce costs.

Table 8-1 – TEMTADS 5x5 Array Tracked Costs

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	 $9,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$15,600 1 40 3 8 $7,300
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$1,600 3 4
Survey Costs	Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$10.64 / anom.** N/A 0.5 2 8 0.5
Processing Costs		**$32.50 / anom.**
Preprocessing	Time required to perform standard data clean up and geophysical data QC.	3 min/anom.
Parameter Estimation	Time required to extract parameters for each anomaly.	12 min/anom.

Table 8-2 – TEMTADS MP 2x2 Cart Tracked Costs

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	 $3,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$12,450 1 16 3 8 $7,250
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$780 3 2
Survey Costs	Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$7.15 / anom.** $190 0.5 2 8 0.5
Processing Costs		**$10.85 / anom.**
Preprocessing	Time required to perform standard data clean up and to merge the location and geophysical data.	3 min/anomaly
Parameter Estimation	Time required to extract parameters for all anomalies.	2 min/anomaly

9.0 SCHEDULE OF ACTIVITIES

Figure 8-1 gives the overall schedule for the demonstration including deliverables.

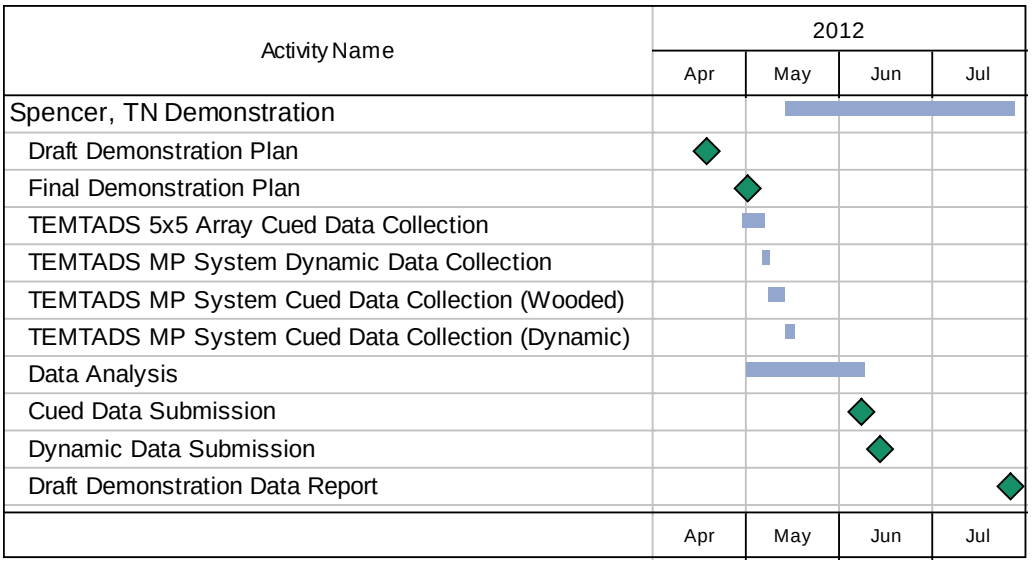

Figure 9-1 – Schedule of all demonstration activities including deliverables.

10.0 MANAGEMENT AND STAFFING

The responsibilities for this demonstration are outlined in Figure 10-1. Dan Steinhurst was the PI of this demonstration. Dan Steinhurst filled the role of Site / Project Supervisor. Tom Bell served as Quality Assurance Officer. Glenn Harbaugh was the Site Safety Officer and Data Acquisition Operator. His duties included data collection and safety oversight for the entire team. Jim Kingdon served as the Data Analyst. Greg Abrams, Harry Wagner, and Brad Boileau of URS Corp. participated in the MP system data collections.

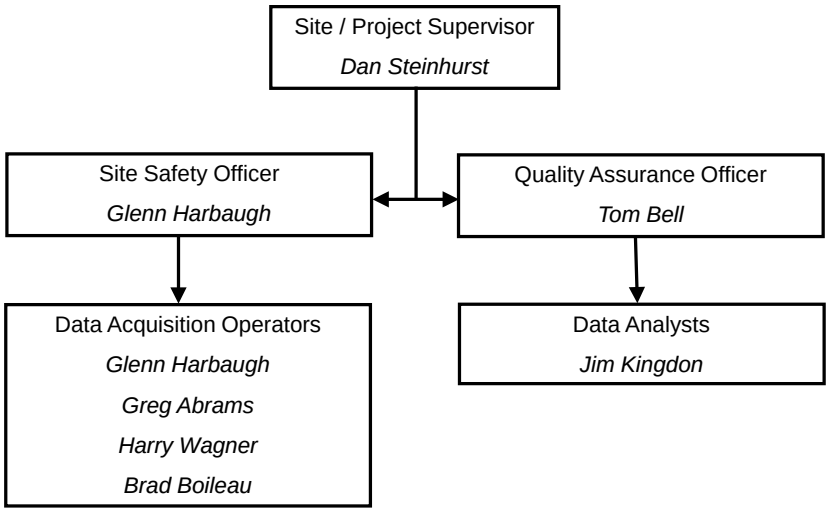

Figure 10-1 – Management and Staffing Wiring Diagram.

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APPENDIX A. HEALTH AND SAFETY PLAN (HASP)

An abbreviated Health and Safety Plan was generated for this demonstration. All emergency information such as contact numbers and directions to nearby medical facilities are provided in that document. The contents are reproduced here.

A.1 DIRECTIONS TO RIVER PARK HOSPITAL

Directions to the River Park Hospital in McMinnville, TN are as follows, starting at the exit from TN-111 to the worksite. See Figure A-1 for the overall route.

1) Head South on TN-111 South for 3.7 miles.
2) Turn Right onto TN-8 North, drive for 19.7 miles.
3) Take a slight Right onto TN-56 North, drive 1.1 miles.
4) Turn Right onto Durham Street, drive for 0.4 miles.
5) Turn Right onto Sparta Street, drive for 0.1 miles.
6) Keep Right at the fork, River Park Hospital is on the Left.

River Park Hospital is located at 1559 Sparta Street, McMinnville, TN 37110, 931-815-4000. The total distance to travel is 26.9 miles and should take 34 minutes.

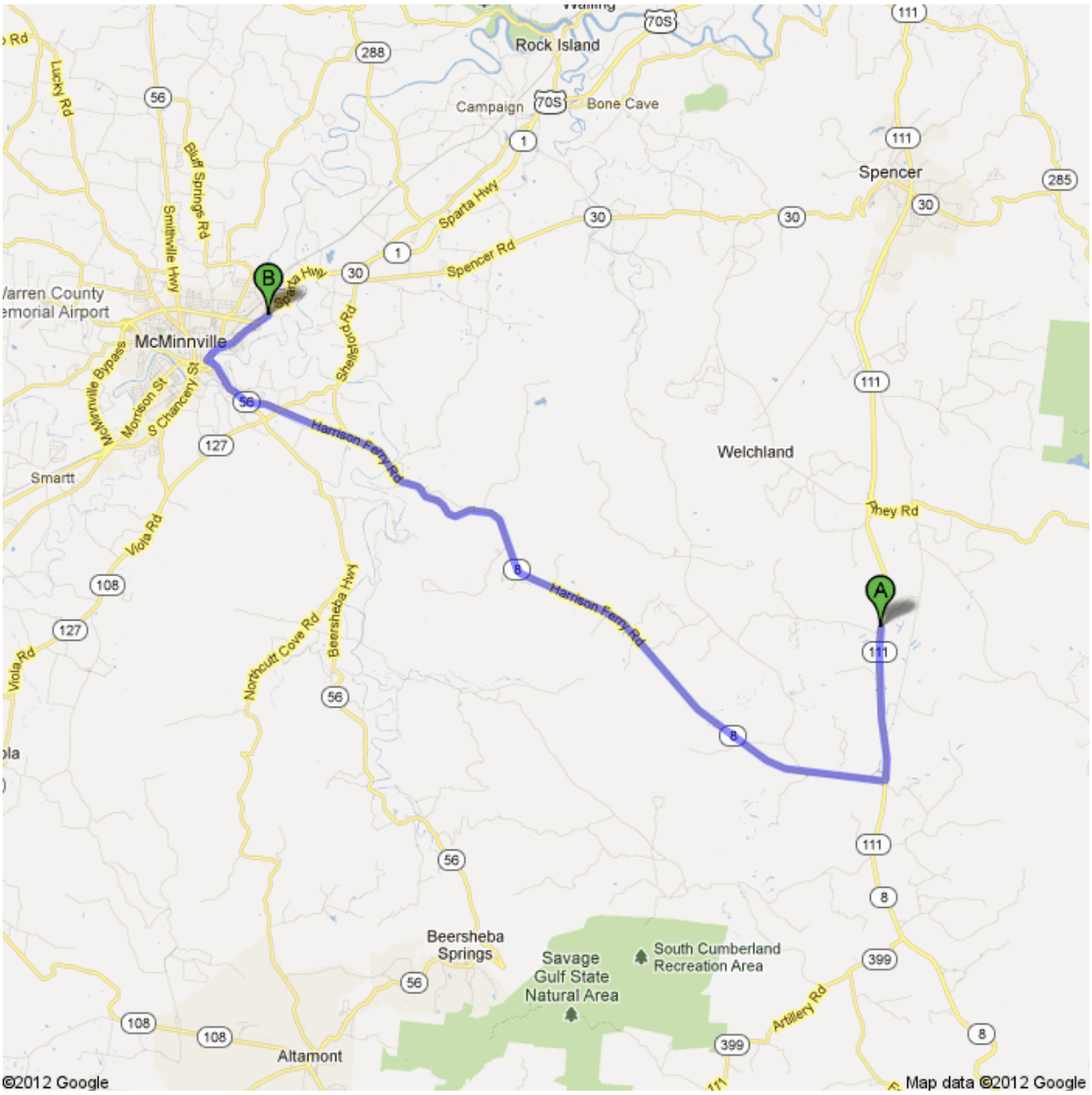

Figure A-1 – Area map showing the location of the River Park Hospital with respect to the work site.

A.2 EMERGENCY TELEPHONE NUMBERS

Telephone numbers for medical fire and other emergencies will be available on site for use by all project personnel in the event of an emergency and are provided in Table A-1. All vehicles will contain a cellular phone (including the phone list) to allow emergency communications in the event of an accident. The telephone area code for this area is 931.

Table A-1 – Emergency Contact Numbers

Agency	Emergency Phone Number	Non-Emergency Phone Number	Location
Spencer Fire Department	911	(931) 946-2332	495 Drake & Shockley Rd., Spencer, TN 38585
Ambulance	911	(931) 946-8181	112 Generations Drive, Spencer, TN 38585
Police Department	911	(423) 447-2197	128 Frazier Street, Pikeville, TN 37367-5765
River Park Hospital		(931) 815-4000	1559 Sparta Street, McMinnville, TN 37110
Spencer Drug Company		(931) 946-7900	120 College Street, Spencer, TN 38585
Tennessee Poison Action Line		(800)-222-1222	http://www.tnpoisoncenter.org

APPENDIX B. POINTS OF CONTACT

POINT OF CONTACT	ORGANIZATION	Phone Fax e-mail	Role in Project
Dr. Jeff Marqusee	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-2120 (V) 703-696-2114 (F) jeffrey.marqusee@osd.mil	Director, ESTCP
Dr. Anne Andrews	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-3826 (V) 703-696-2114 (F) anne.andrews@osd.mil	Deputy Director, ESTCP
Dr. Herb Nelson	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-8726 (V) 703-696-2114 (F) 202-215-4844 (C) herbert.nelson@osd.mil	Program Manager, MR
Ms. Katherine Kaye	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	410-884-4447 (V) kkaye@hgl.com	Program Manager Assistant, MR
Mr. Daniel Ruedy	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	703-736-4531 (V) druedy@hgl.com	Program Manager's Assistant, MR
Dr. Dan Steinhurst	Nova Research, Inc. 1900 Elkin St., Ste. 230 Alexandria, VA 22308	202-767-3556 (V) 202-404-8119 (F) 703-850-5217 (C) dan.steinhurst@nrl.navy.mil	PI
Mr. Glenn Harbaugh	Nova Research, Inc. 1900 Elkin St., Ste. 230 Alexandria, VA 22308	804-761-5904 (V) glenn.harbaugh.ctr@nrl.navy.mil	Site Safety Officer
Dr. Tom Bell	SAIC 4001 N Fairfax Dr., Room 675 Arlington, VA 22203	703-312-6288 (V) 301-712-7021 (C) thomas.h.bell@saic.com	Quality Assurance Officer
Ms. Victoria Kantsios	URS Group, Inc. 2450 Crystal Drive, Suite 500 Arlington, VA 22202	703-418-3030 (V) 703-418-3040 (F) victoria_kantsios@urscorp.com	URS Project Lead

APPENDIX C. TEMTADS 5X5 ARRAY DATA FORMATS

C.1 POSITION / ORIENTATION DATA FILE (*.GPS)

```
Antenna,X_Offset,Y_Offset,Z_Offset,Easting/Yaw,Northing/Pitch,HAE/Range
Main,0.000,1.365,0.730,316256.990,4254211.094,-25.934
AVR1,-0.778,-1.418,0.740,3.40349,0.00761,2.882
AVR2,0.778,-1.418,0.745,1.55718,0.00425,1.554
```

These data files are ASCII format, comma-delimited files. A header line is provided.

Line 1 – Header information

Line 2 – Main GPS antenna data

```
Main              - Antenna Identifier
0.000             - Cross-track distance from array center
1.365             - Down-track distance from array center
0.730             - Vertical distance from array center
316256.990        - Easting (UTM, m) position of Main antenna
4254211.094       - Northing (UTM, m) position of Main antenna
-25.934           - Height-above-ellipsoid (m) position of Main antenna
```

Line 3 & 4 – AVR GPS antenna data (AVR1 as example)

```
AVR1              - Antenna Identifier
-0.778            - Cross-track distance from array center
-1.418            - Down-track distance from array center
0.740             - Vertical distance from array center
3.40349           - Yaw of AVR vector (radians, True North referenced)
0.00761           - Pitch of AVR vector (radians)
2.882             - Range of AVR vector (m)
```

C.2 TEM DATA FILE (*.TEM)

These data files are a binary format generated by a custom .NET serialization routine. They are converted to an ASCII, comma-delimited format in batches as required. Each file contains 25 data points, corresponding to each Tx cycle. Each data point contains the Tx transient and the corresponding 25 Rx transients as a function of time. A pair of header lines is also provided for, one overall file header and one header per data point with the data acquisition parameters. A partial example is provided below.

Line 1 - File Header

```
CPUms,PtNo,LineNo,Delt,BlockT,nRepeats,DtyCyc,nStk,AcqMode,GateWid,Gate
HOff,TxSeq,GateT,TxI_Z,Rx0Z_TxZ,Rx1Z_TxZ,Rx2Z_TxZ,Rx3Z_TxZ,Rx4Z_TxZ,Rx5
Z_TxZ,Rx6Z_TxZ,Rx7Z_TxZ,Rx8Z_TxZ,Rx9Z_TxZ,Rx10Z_TxZ,Rx11Z_TxZ,Rx12Z_TxZ
,Rx13Z_TxZ,Rx14Z_TxZ,Rx15Z_TxZ,Rx16Z_TxZ,Rx17Z_TxZ,Rx18Z_TxZ,Rx19Z_TxZ,
Rx20Z_TxZ,Rx21Z_TxZ,Rx22Z_TxZ,Rx23Z_TxZ,Rx24Z_TxZ,
```

Line 2 - Data Point Header

```
0,1,0,2E-06,0.9,9,0.5,3,2,0.05,5E-05,22,

0           - Start time in ms on CPU clock (always 0)
1           - Data Point Number (always 1)
0           - Line Number (always 0)
2E-06       - Time step for transients (seconds)
0.9         - Base period length (seconds)
9           - Number of Tx cycles in a base period
0.5         - Duty cycle
3           - Number of base periods averaged (or stacked)
2           - Data Acquisition Mode (binned)
0.05        - Gate width as fraction of its own time
5E-05       - Hold-off time (seconds) for first data point
22          - Tx ID number (sensor number + 10)
```

Line 3 - First Data Line in First Data Point

```
,,,,,,,,,,,,2.5E-05,2.01102465120852,-4.71949940100108E-05,-
1.79793904939509E-05,1.39366551389817E-05,-2.55470612811271E-05,-
4.84779418501355E-05,4.05641650778409E-05,6.73185201421361E-06,-
0.000116516308079121,-2.49295973312366E-06,4.21216420108736E-
05,3.70976690069955E-05,-0.000127606649206979,-0.000510366345393333,-
0.000100251591870083,5.19149917311475E-05,3.71239440686929E-05,-
6.05368361143584E-06,-0.000125671808025774,2.44747669528873E-
05,5.7401043406257E-05,-5.14479298585597E-05,-9.42595187481444E-
06,3.27817636140336E-05,-1.1886747308274E-05,-5.57022247620241E-05,
```

C.3 ANOMALY PARAMETER OUTPUT FILE

The MTADS DAS will be used to analyze TEMTADS data. The fitted parameters for each investigated anomaly are distributed as an Excel 2003 spreadsheet, but an excerpt is given in .csv format below for reference purposes. A header line is provided for information followed by a 116-line block for each anomaly. The first line of each block contains the time gate-independent fit parameters and the remaining 115 contain the time gate-dependent parameters for each anomaly.

```
Anomaly_ID,Anomaly_X,Anomaly_Y,Anomaly_Amplitude,Fit_X,Fit_Y,Fit_Depth(
m),Fit_Phi(deg),Fit_Theta(deg),Fit_Psi(deg),Fit_Coherence,Time_Gate,Bet
a1,Beta2,Beta3

28,402751.00,4369521.75,234.34,402750.926,4369521.686,0.151,250.42,2.02
,76.57,0.99612,,,,
,,,,,,,,,,,1,1.47E+00,1.05E+00,1.08E+00
,,,,,,,,,,,,,,,,,,
,,,,,,,,,,,,,,,,,,
,,,,,,,,,,,,,,,,,,
,,,,,,,,,,,115,2.46E-05,-1.69E-05,-1.60E-04

33,402726.00,4369505.50,15.24,402725.835,4369505.588,0.422,96.25,16.45,
5.26,0.96448,,,,
,,,,,,,,,,,1,1.71E+00,1.23E+00,1.18E+00
,,,,,,,,,,,,,,,,,,
,,,,,,,,,,,,,,,,,,
,,,,,,,,,,,,,,,,,,
,,,,,,,,,,,115,6.56E-04,-1.91E-03,-1.57E-04
```