DEMONSTRATION REPORT

Data Collection using the MetalMapper in Dynamic Data Acquisition and Cued Modes

TEMTADS Surveys at Redstone Arsenal
Huntsville, Alabama

ESTCP Project MR-201420

MAY 2017

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1. REPORT DATE *(DD-MM-YYYY)* 06-20-2017	**2. REPORT TYPE** Final	**3. DATES COVERED** *(From - To)* Oct 2015 – Dec 2016
4. TITLE AND SUBTITLE Demonstration Report Demonstration of Advanced Geophysics and Classification Technologies on Munitions Response Sites TEMTADS Surveys at Redstone Arsenal Huntsville, Alabama		**5a. CONTRACT NUMBER** W912HQ-14-C-0022 **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Takata, Sandra Flemmer, Jeremy Nycum, Charles Gritz, Andrew Chang, Colin		**5d. PROJECT NUMBER** 500239 **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) CB&I One CB&I Plaza 2103 Research Forest Drive The Woodlands, TX 77380		**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Environmental Security Technology Certification Program 4800 Mark Center Drive, Suite 17D03 Alexandria, VA 22350-3605 U.S. Army Garrison-Redstone Madison County, Alabama		**10. SPONSOR/MONITOR'S ACRONYM(S)** ESTCP **11. SPONSOR/MONITOR'S REPORT NUMBER(S)** 500239

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The objectives of this project were to demonstrate the ability to collect data in dynamic and cued modes for MEC detection and identification using the TEMTADS, while simultaneously transferring the technology from researchers to production companies, and to gain regulatory acceptance.

15. SUBJECT TERMS

Advanced Geophysical Classification, MMRP, TEMTADS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
Unlimited					Sandra Takata
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	Unlimited	85	**19b. TELEPHONE NUMBER** *(include area code)*
Unlimited	Unlimited	Unlimited			865.560.7940

Standard Form 298 (Rev. 8-98)
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Project: MR-201420

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ACRONYMS AND ABBREVIATIONS

β1, β2, β3	Polarizabilities along Three Principal Axes of Anomalies
μs	Microsecond(s)
Acorn	Acorn Geophysical Services Ltd.
ADEM	Alabama Department of Environmental Management
CB&I	CB&I Federal Services LLC
cm	Centimeter(s)
DAVS	Detector-aided Visual Survey(s)
DGM	Digital Geophysical Mapping
EM61-MK2	Geonics Ltd. High-sensitivity Metal Detector
ERT, Inc.	Environmental Remediation Technologies, Inc.
ESTCP	Environmental Security Technology Certification Program
FM	Titanium Tetrachloride
Geosoft	Geosoft Inc.
GPS	Global Positioning System
HE	High Explosive
ID	Identification
IM-AE	Isobutyl Methacrylate Incendiary Mix
IMU	Inertial Measurement Unit
ISO	Industry Standard Object
IVS	Instrument Verification Strip
MD	Munitions Debris
MEC	Munitions and Explosives of Concern
mm	Millimeter(s)
MPPEH	Material Potentially Presenting an Explosive Hazard
MQO	Measurement Quality Objectives
ms	Millisecond(s)
mV/A	Millivolts per Ampere
NRL	U.S. Naval Research Laboratory
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control

RMS	Root Mean Square
ROC	Receiver-operating Characteristic
RSA	Redstone Arsenal
RTS	Robotic Total Station
SFTP	Secure File Transfer Protocol
TDEM	Time-domain Electromagnetic
TEMTADS 2x2	Time-domain Electromagnetic Multi-sensor Towed Array Detection System
TOI	Target(s) of Interest
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
WP	White Phosphorous

1.0 INTRODUCTION

CB&I Federal Services LLC (CB&I), working for the Environmental Security Technology Certification Program (ESTCP) under Contract No.W912HQ-14-C-0022, performed a Live Site Demonstration Data Collection Project using the Time-domain Electromagnetic Multi-sensor Towed Array Detection System 2x2 (TEMTADS) in dynamic and cued data acquisition modes. ESTCP chose Redstone Arsenal (RSA) located in Huntsville, Alabama, as a live site as proposed by the U.S. Army Engineering and Support Center, Huntsville (USAESCH).

The objectives of this project were as follows: 1) to demonstrate the ability to collect data in dynamic and cued modes for munitions and explosives of concern (MEC) detection and identification using the TEMTADS, while simultaneously transferring the technology from researchers to production companies; and 2) to gain regulatory acceptance.

The subject area, RSA-073, is within RSA-312 (**Figure 1-1**). The entire site is approximately 50.6 acres, and RSA-073 is approximately 8.5 acres. Prior to the ESTCP demonstration, Time-domain Electromagnetic (TDEM) high-sensitivity metal detector (EM61-MK2) surveys were performed over RSA-073 and twenty-four 100-foot by 100-foot grids in RSA-312 by Environmental Remediation Technologies, Inc. (ERT, Inc.). Additionally, detector-aided visual surveys (DAVS) were performed in 2014. Site assessments by the USAESCH show the probability for encountering unexploded ordnance (UXO) to be "moderate/high."

Areas east of Anderson Road were used for explosives training and munitions testing, and as impact areas for 4.2-inch mortars, large caliber projectiles (75-millimeter [mm] to 155-mm), and numerous types of bombs. With the exception of some areas north of RSA-312-R-01 and former RSA-073, the majority of the areas west of Anderson Road to the RSA boundary were safety/buffer zones. A review of available historical photographs identified only limited activities occurring in areas west of Anderson Road. RSA-073 is not a known impact area; however, land scarring/craters are visible in RSA-073 in the Light Detection and Ranging data set. The MEC reportedly used in RSA-073 includes: AN-M76 bombs, PT1 (incendiary mixture similar to Goop) filled; M47-type bombs, isobutyl methacrylate incendiary mix (IM-AE) and napalm filled; M69 bombs, IM-AE filled; 155-mm projectiles, white phosphorus (WP) and titanium tetrachloride (FM) filled; 105-mm WP projectiles; 81-mm projectiles, WP and high explosives (HE) filled; 75-mm FM projectiles; 40-mm HE projectiles; and M5 bursters. In addition, RSA-073 is within a safety/buffer zone for 4.2-inch mortars and large caliber projectiles (75-mm to 155-mm). These are the potential targets of interest (TOIs).

DAVS were performed at RSA-312-R-01 (including the former RSA-073) in the spring of 2014. The DAVS was performed at a 5-foot line spacing across 100 percent of the accessible areas of the site using a system of 100-foot by 100-foot grids (**Figure 1-2**). During the DAVS, 100 surface and 2,858 subsurface anomalies were recorded, and 2.25 pounds of munitions debris (MD) and 200.95 pounds of metallic debris were removed from the surface of the site. **Figure 1-2** presents the number of subsurface anomalies recorded within each grid. During the survey, part of an AN-M50 thermite bomb was discovered on the surface in DAVS Grid R-13, which is west of the demonstration area. It was reported that no fuse or explosives were evident, and that thermite residue may have been present in the item. No MEC or features such as craters, disturbed ground, etc., were found on the surface of any of the accessible areas across the entire site.

Currently, the site is not being actively used; it is a buffer area for Test Areas 3 and 6. The future land use is expected to be part of the Gate 7 expansion, and for research and development and testing and evaluation of munitions.

CB&I's primary goal was to detect and correctly classify MEC items in a wooded area where the TEMTADS was integrated with a robotic total station (RTS) for navigation. Intrusive activities followed the classification of anomalies as part of efforts in the larger RSA-312 site.

1.1 BACKGROUND

The ability to safely and efficiently locate, identify, and remove buried objects on practice and test ranges is critical to the U.S. Department of Defense mission and its goals of safe operation, sustainability, and environmental stewardship. Although several robust, advanced sensor technologies have been developed for discriminating buried objects on ranges as TOIs, widespread acceptance of the technologies requires that they be demonstrated on live sites, where the impact of operating and data acquisition and analysis parameters can be fully evaluated. The potential benefit of the technology is to reduce the number of subsurface investigations that are required to remove hazardous MEC in areas where subsurface clearance is required.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objectives of this project were as follows:

- Collect dynamic and cued TEMTADS data in a highly wooded area
- Prioritize the anomaly list
- Classify all TOIs
- Collect operational data (production and cost) that can be applied to planning future projects
- Provide training for project geophysicists in the use of the hardware and classification software, thereby facilitating the transfer of technology from researchers to production companies
- Provide data that will assist in gaining regulatory acceptance of the advanced classification technologies
- Detect and classify large munitions, such as 4.2-inch mortars, at a depth of approximately 90 centimeters (cm)

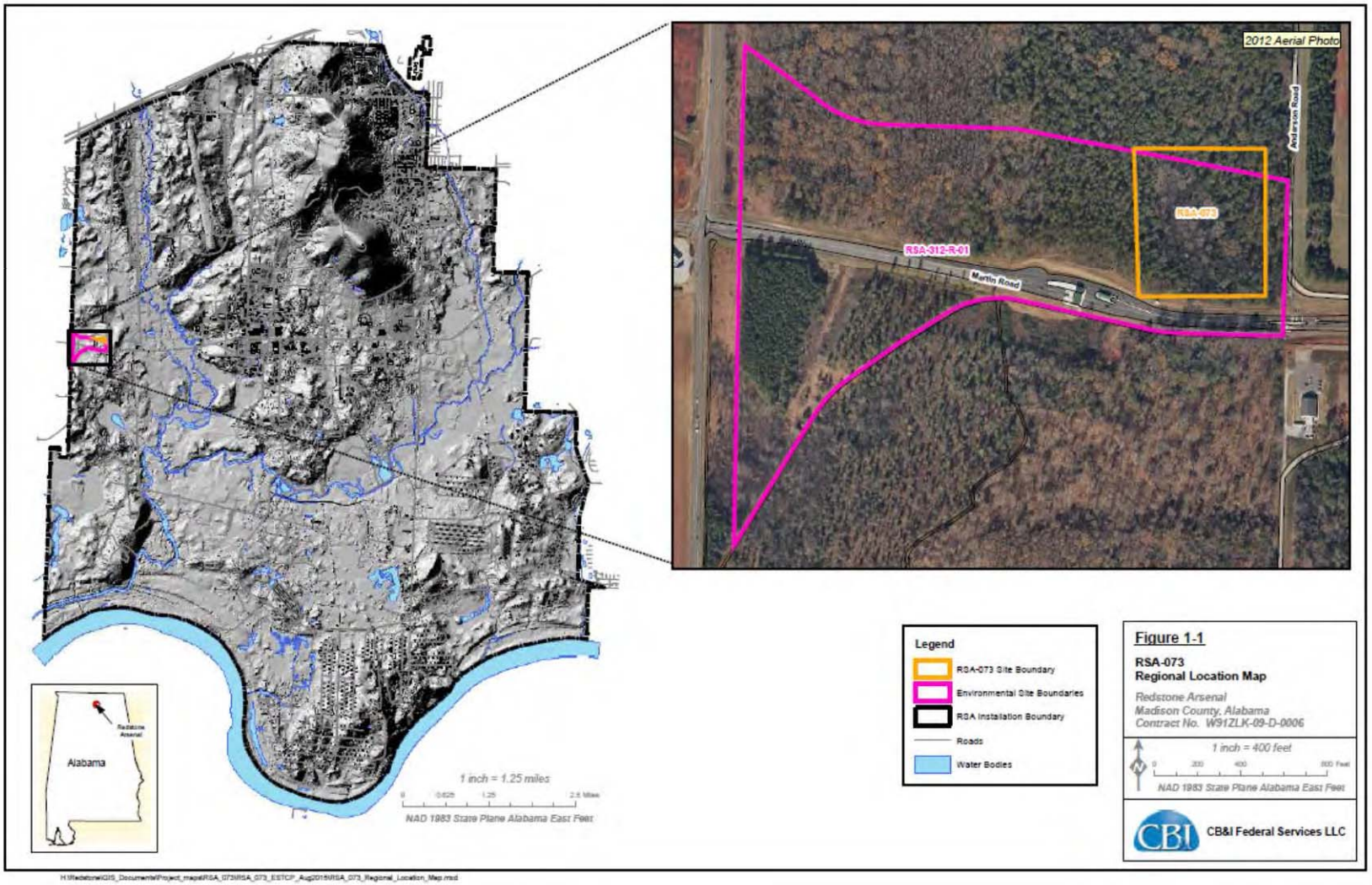

Figure 1-1 Location of RSA-073 at Redstone Arsenal

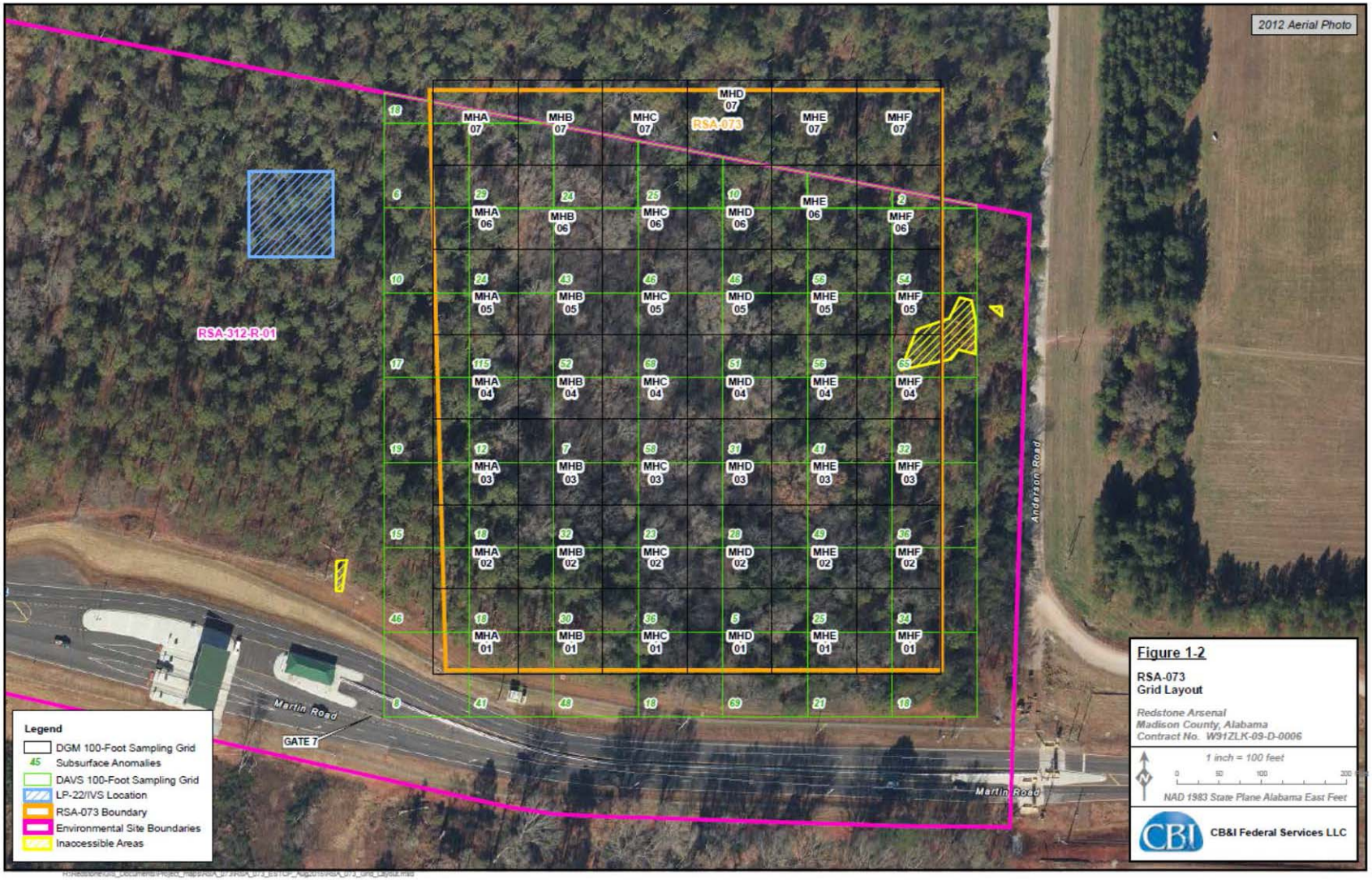

Figure 1-2 Grid Layout and Subsurface Anomaly Counts

To meet these objectives, CB&I geophysicists were trained by U.S. Naval Research Laboratory (NRL) representatives in the use of the TEMTADS to collect data in dynamic and cued modes. For this demonstration, CB&I collected 8.21 acres of dynamic data, and cued measurements over 1,178 anomalies identified in the dynamic data. CB&I geophysicists processed the data and performed advanced classification interpretation techniques to generate a prioritized dig list using Geosoft Inc.'s (Geosoft) UX-Analyze software extension under the guidance of Acorn Geophysical Services Ltd. (Acorn) geophysicists. By developing a prioritized dig list, ranging from "high-confidence TOI" through "can't analyze", "inconclusive", and "high-confidence non-TOI", CB&I will demonstrate the ability of advanced classification technologies to significantly reduce the number of excavations of non-UXO anomalies.

1.3 REGULATORY DRIVERS

In general, advanced classification sensors, data processing, and interpretation methods are new technologies gaining momentum for acceptance with regulatory agencies. Acceptance from the regulators will result in classification technologies being used at more clean-up sites, which will equate to reduced numbers of excavations and in turn, can ultimately reduce the overall costs of remedial actions.

The Munitions Response Program at RSA is conducted under the oversight of the Alabama Department of Environmental Management (ADEM). ADEM is familiar with advanced classification sensors, data processing, and interpretation methodology, and they welcomed the demonstration in RSA site conditions.

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2.0 TECHNOLOGY

Hardware for TDEM data collection in both dynamic and cued modes included a NRL TEMTADS and a Trimble S7 RTS positioning system. This equipment was deployed as a man-portable unit for fast and efficient data collection. UX-Analyze developed by Acorn and Geosoft was used to perform TEMTADS data quality control (QC) checks, processing, and interpretation.

2.1 TECHNOLOGY DESCRIPTION

The TEMTADS is an advanced TDEM sensor designed specifically for classification of MEC items. This system is built from polyvinyl chloride (PVC) and fiberglass, and the receivers are mounted on a wheeled cart. The positioning sensor rests on a five-legged platform above the center of the system. The data-acquisition computer and electronics are mounted in the operator's backpack.

The photo on **Figure 2-1** shows the TEMTADS with an RTS prism, elevated to avoid the instrument operator obstructing the laser, and inertial measuring unit (IMU). A schematic of the electromagnetic induction sensor array showing the position of the four sensors is also illustrated on **Figure 2-1**. The orientation of the sensor cubes are indicated relative to the forward direction of travel.

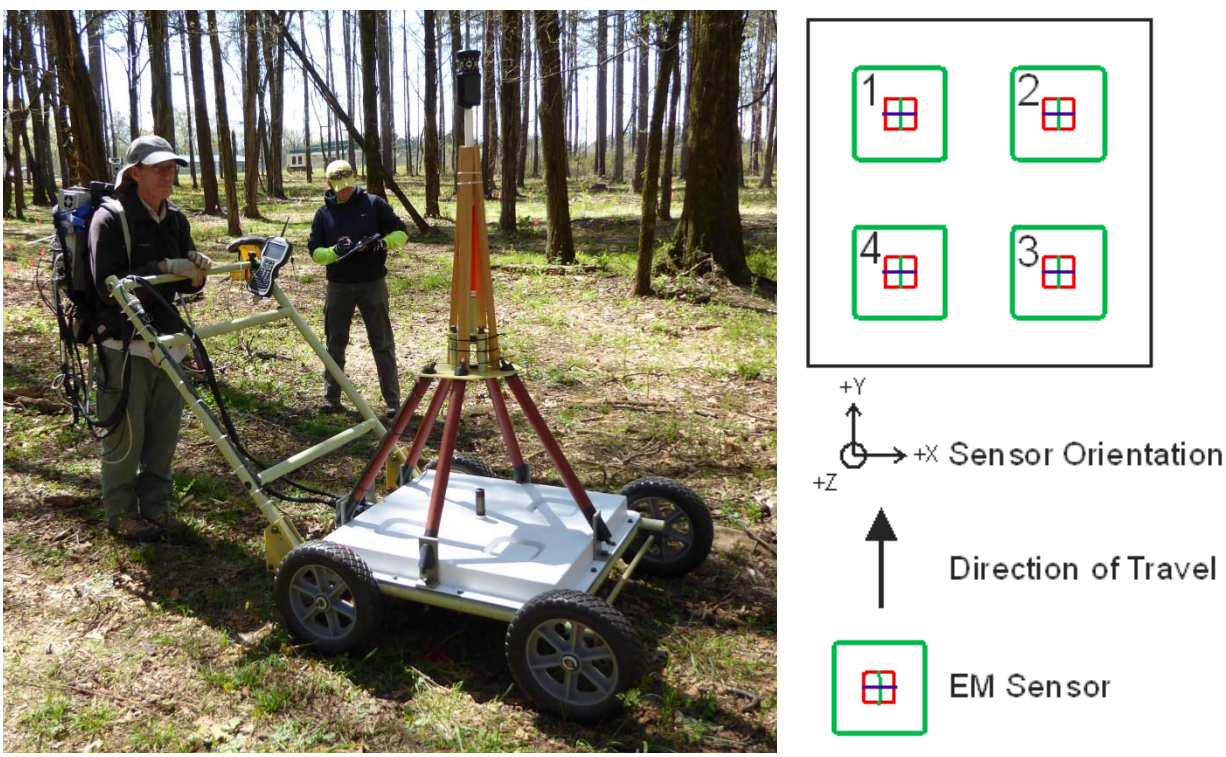

Figure 2-1 TEMTADS with RTS Navigation and Hardware Schematic

The center-to-center distance of the sensors is 40 cm in both the x and y directions. The array size is 80 cm by 80 cm. It is deployed on a set of wheels so that the sensors are 20 cm above the ground. The transmitter electronics and the data-acquisition computer are mounted in the operator backpack. A second person runs the control software over a wireless connection to a tablet. There are two modes of operation: dynamic and cued modes. Data collection is controlled in dynamic mode using G&G Science's EM3D application suite in dynamic mode. In cued mode, data collection is performed with NRL software.

Decay data are collected at a rate of 500 kilohertz after turn-off of the excitation pulse for up to 25 milliseconds (ms). This results in a raw decay of up to 12,500 points, which are grouped into logarithmically-spaced "gates" with center times ranging from 25 microseconds (µs) to 24.35 ms with proportional widths. The data are saved to disk.

The design allows the TEMTADS to interrogate subsurface objects from a variety of angles and distances, and subsequently perform advanced analysis of the received signals to provide quantitative information on the shape and electrical properties of the source object.

During this demonstration, a list of anomalies detected during the dynamic TEMTADS survey was generated. Each anomaly was relocated using the RTS and cued data were collected at each anomaly location. For cued data collection, the cart was positioned over each target, the transmitter for each sensor fired in sequence automatically, and decay data were collected and stored on the data-acquisition computer. The operator evaluated a display of the four monostatic, three-axis signal amplitude decays and the symmetry of the responses, and compared values at the first usable time gate (89 µs) to a 'low signal to noise ratio' threshold. The data was then processed using a single-dipole inversion routine to extract target location and shape parameters. The offset between the center of the array location and the inverted location was compared. If the fit location was outside of the specified tolerance of 40 cm, the operator would reposition the array to the inverted location and collect additional data prior to moving to the next target. **Figure 2-2** shows the data collection and field inversion software screen from the cued TEMTADS setup.

Figure 2-2 Field Inversion Software Screenshot

TEMTADS data processing, data QC, and target selection were accomplished using UX-Analyze. UX-Analyze was also used for data visualization, data inversion, QC of inversion results, target classification, training data selection, and dig-list creation. The software was developed by Acorn and Geosoft with funding from ESTCP. **Figure 2-3** shows a screen capture from UX-Analyze during the interactive classification process, where library matches, physical characteristics, and fit parameters are reviewed for the purpose of ranking each target.

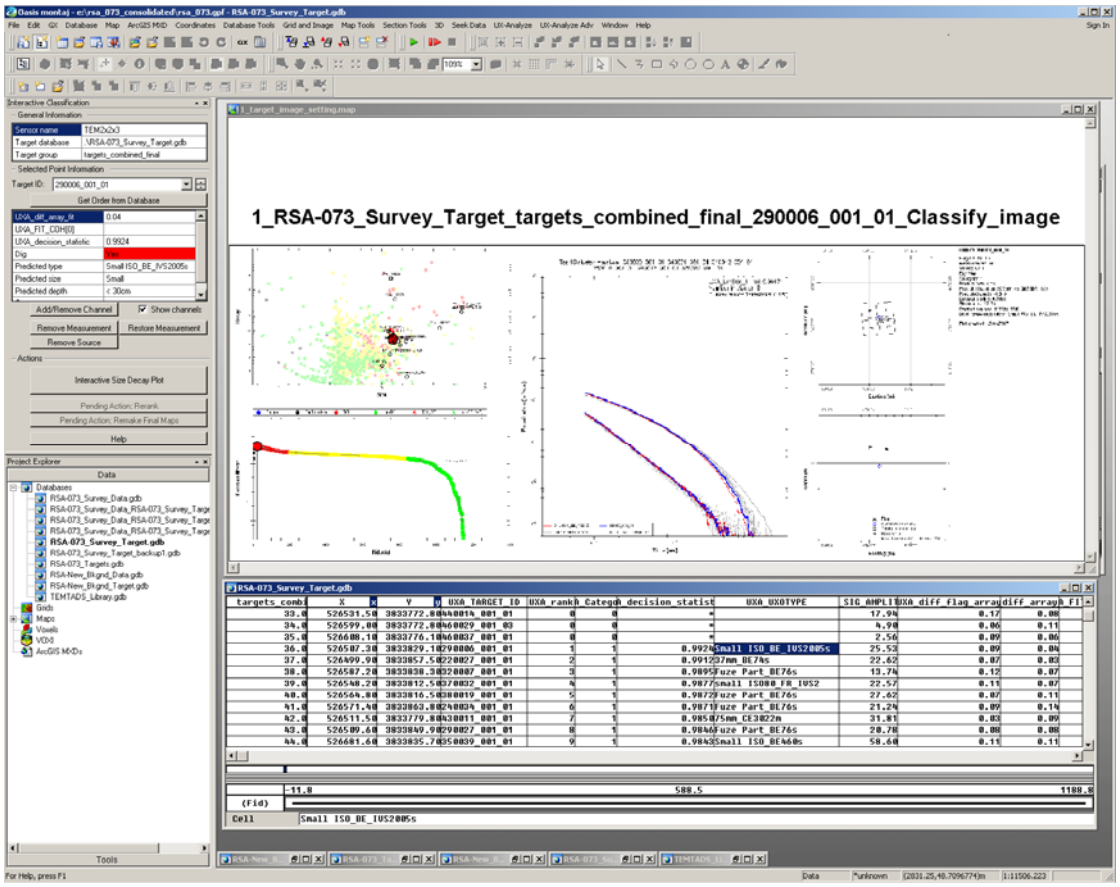

Figure 2-3 UX-Analyze Interactive Classification Screenshot

Once all the anomalies are classified and intrusive data are collected, the analyst's results can be plotted on a receiver-operator characteristic (ROC) curve, and an evaluation of the success of digging all TOIs while reducing digs of non-TOI may be made. ROC curves are used for evaluation. The analyst's stop dig point and the plot of the last TOI on the dig list can be compared. The steeper the curve near the origin of the plot, the better the analyst was in finding all the TOI and reducing the amount of clutter dug. Due to the limited number of intrusive investigations made at RSA-073, no ROC curve was made for this demonstration.

Considerable advancements have been made in discrimination technology. Testing of the TEMTADS has been primarily focused on integration with global positioning system (GPS) for cued data collection at test sites, using well-known and accepted instruments in mostly controlled conditions for anomaly identification. At RSA-073 the TEMTADS was coupled with an RTS and is being tested as the primary anomaly-detection instrumentation.

The technology is being validated at sites with various munitions types and site conditions, and thereby being transitioned from research environments to production companies to prove the dynamic data-collection deployment. Concurrently, the TEMTADS development continues to increase its robustness and internal QC testing. It is expected that the technology will continue to gain regulatory and industry acceptance in the near term.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Currently, advanced classification survey instruments include the MetalMapper, TEMTADS and Man Portable Vector. The main advantage of the MetalMapper is that it is commercially available, while the others have limited availability as primarily research instruments. A second generation MetalMapper is now available and is largely based on the TEMTADS design. Advantages of advanced classification instrumentation are as follows:

- Advanced classification instruments are multi-transmitter/receiver systems so that a target is illuminated from multiple directions simultaneously.
- Dynamic data are used for detection and may be used for classification in a single data-collection event, though this capability is currently being integrated into UX-Analyze.
- Cued data are high-fidelity and allow high-quality and accurate inversions for anomaly classification.
- Library matching tools allow for quick, easy, and reliable classification of anomalies.
- Dig-lists are classified and prioritized anomalies. This results in fewer digs of non-TOI.

Limitations are as follows:

- The system is 80 cm by 80 cm and mounted on a cart so areas where access is limited due to terrain or vegetation density may be an issue.
- Dynamic data collection is slower and therefore more expensive than conventional EM61 surveys.
- Cued data collection requires a previous dynamic survey (either conventional digital geophysical mapping [DGM] or advanced classification sensor) to detect anomalies, thus resulting in increased geophysical survey costs.
- Updated polarizability libraries weren't available at the time of this survey but will be released soon.

3.0 PERFORMANCE OBJECTIVES

The performance objectives are summarized in **Table 3-1**. The objective and the associated metric, data-collection events, and success criteria are also presented. A description of each follows the table.

Table 3-1 Performance Objectives

Performance Objective	Metric	Data Required	Success Criteria
Data Collection Objectives			
IVS repeatability	Location and detection amplitudes are repeatable	Dynamic and cued IVS data	Dynamic: Detection amplitudes are within 25%. Locations are within 0.25 meter. Cued: Library match to initial polarizabilities metric ≥ 0.90 for each set of three inverted polarizabilities. All IVS item fit locations within 0.25 meter of ground truth locations
Dynamic data full-coverage survey	Across-track line separation Along-line data separation	Dynamic data	90% across-track separation is within 0.5 meter. 100% are within 0.7 meter. 95% along-line data separation is within 15 cm. 100% are within 20 cm. Metrics exclude obstructed areas.
TOI detection	Detection of seed items	Dynamic data	100% of seed items detected.
Cued data location	Distance between cued location setup and the inverted location	Cued data	Locations within 40 cm.
Data Analysis Objectives			
Correctly classify TOIs	Identify TOI and seed items	Cued data and excavation results	100% of seed items correctly classified Correctly classify 100% of TOIs.
Correctly classify non-TOIs	Eliminate false alarms	Cued data and excavation results	70% of non-TOIs correctly classified
Minimize "can't analyze" anomalies	High quality cued data	Cued data	Less than 5% "can't analyze" anomalies.
Correctly place the stop-dig threshold	TOIs above stop-dig threshold	Prioritized dig sheet and excavation results	No TOI below threshold. Minimize non-TOI digs above threshold.
Correct anomaly locations	Anomaly locations on dig list are accurate.	Detection, inversion and excavated locations	Detected location and inversion location are within 40 cm. Excavated location is within 25 cm of inversion location.

% = percent
cm = centimeter
IVS = instrument verification strip
TOI = target of interest

3.1 OBJECTIVE: INSTRUMENT VERIFICATION STRIP REPEATABILITY

The effectiveness of the technology for detection and classification of munitions is dependent on high-fidelity data that are defensible and repeatable.

3.1.1 Metrics

TEMTADS settings and survey parameters are used such that consistent detection and location of instrument verification strip (IVS) seed items are realized.

3.1.2 Data Requirements

Dynamic and cued data are collected at the IVS before and after each day's production surveying. Detection data are processed and then compared for repeatable amplitudes and location control. Cued data polarizability curves are matched to the library items and to the initial IVS results.

3.1.3 Success Criteria

The objectives are met if detection amplitudes are within ± 25 percent, and interpreted locations are within 0.25 meter of the ground truth location of the seed items. The objectives are met for cued surveys if library match to polarizabilities metric ≥ 0.90 and are located within 0.25 meter of ground truth locations.

3.2 OBJECTIVE: DYNAMIC DATA FULL-COVERAGE SURVEY

The detection of all munitions depends on ample detection survey coverage. The coverage for both across-track line separation and along-line data separation are included in coverage.

3.2.1 Metric

TEMTADS settings and survey parameters are used such that consistent detection and location of IVS seed items are realized.

3.2.2 Data Requirements

TEMTADS dynamic data are collected with integrated navigation. Data are processed using project procedures determined during IVS data collection. Plan maps are plotted to confirm data cohesiveness. Line-to-line and along-line data points are reviewed for quality and data gaps, and the results documented. Data gaps are marked for fill-in data collection.

3.2.3 Success Criteria

The objectives are met if 90 percent across-track line separation is within 0.5 meter and 100 percent is within 0.7 meter, and 95 percent along-line data are within 15 cm and 100 percent are within 20 cm. This excludes obstructed areas.

3.3 OBJECTIVE: TOI DETECTION

The detection of all TOI is a desired objective.

3.3.1 Metric

TEMTADS settings and survey parameters are used such that consistent detection and location of IVS and blind seed items are realized.

3.3.2 Data Requirements

The dynamic data are collected with integrated navigation. Data are processed using the project selection criteria. IVS and blind seeds are among all selected anomalies.

3.3.3 Success Criteria

The objectives are met if 100 percent of blind seeds are detected and 100 percent IVS seeds are detected and within metrics outlined in the IVS repeatability objective. This metric is to confirm the detection system and to ensure the analyst is meeting these standards for known items.

3.4 OBJECTIVE: CUED DATA LOCATION

The detection location (dynamic) of all anomalies are near inverted locations (cued) is a desired objective.

3.4.1 Metric

TEMTADS setup on the reacquired location of the detection survey is coincident with the location based on the inversion of the cued data.

3.4.2 Data Requirements

The TEMTADS is set up on the reacquired location and cued data are collected. Data are checked in the field using TEMTADS software and the TEMTADS is moved to the revised location, if necessary, that results from the data modelled in the field. Cued data are then collected for classification.

3.4.3 Success Criteria

The objectives are met if 100 percent of the targets' modeled locations are within 40 cm of the center of the TEMTADS. Those that are greater than 40 cm will be recollected at the modeled source location. If the offset is still 40 cm, it will be assumed that this second modeled location is due to a second nearby target and the data are considered a success.

3.5 OBJECTIVE: CORRECTLY CLASSIFY TOIS

This objective requires the correct classification of all TOI including seed items detected in the TEMTADS data.

3.5.1 Metric

TOI items found during the intrusive investigation are identified as such and were identified for digging.

3.5.2 Data Requirements

The cued TEMTADS data are collected at each anomaly detected in the dynamic data, processed, and, using signature library matching and training data, a prioritized dig list is created. The dig list categorizes each anomaly as "high-confidence TOI," "high-confidence non-TOI," and "can't analyze."

3.5.3 Success Criteria

The objective is met when all the TOI and seed items are identified for intrusive investigation. Any "can't analyze" anomalies will also be included on the dig list. 100 percent of TOI are correctly classified.

3.6 OBJECTIVE: CORRECTLY CLASSIFY NON-TOIS

The detected anomalies that are not TOI are classified as non-TOI. This objective shows the effectiveness of the classification system at reducing the number of excavations.

3.6.1 Metric

Only a percentage of non-TOI-classified items are dug, and most non-TOI items are identified as such and are not identified for digging.

3.6.2 Data Requirements

The cued TEMTADS data are collected at each anomaly detected in the dynamic data, processed, and, using signature library matching and training data, a prioritized dig list is created. The dig list categorizes each anomaly as "high-confidence TOI," "high-confidence non-TOI," and "can't analyze."

3.6.3 Success Criteria

The objectives are met if 70 percent of non-TOIs are correctly classified.

3.7 OBJECTIVE: MINIMIZE "CAN'T ANALYZE" ANOMALIES

When data cannot be analyzed, the anomaly cannot be classified. These anomalies must be dug, thus increasing the number of digs, potentially digging non-TOI, and reducing the effectiveness of the advanced classification program.

3.7.1 Metric

Only a small number of "can't analyze" anomalies is the metric.

3.7.2 Data Requirements

The cued TEMTADS data are collected following best practices at each anomaly to minimize the number of anomalies that can't be analyzed, and to maximize the number of anomalies that can be reliably classified.

3.7.3 Success Criteria

The objectives are met if 95 percent of all the anomalies have clean, reliable data, therefore leaving 5 percent of cued data classified as "can't analyze." Additionally, CB&I expected that the analyst would classify 5 percent of the anomalies as "can't decide."

3.8 OBJECTIVE: CORRECTLY PLACE THE STOP-DIG THRESHOLD

The "stop dig" threshold is the dividing line between the digs and the no-digs. The objective is that all TOI, seed items, "can't analyze" anomalies, and validation anomalies are above the stop-dig threshold and the non-TOI are below it. This objective shows the effectiveness of the classification system at reducing the number of excavations.

3.8.1 Metric

All TOI, seed items, "can't analyze," and validation-check anomalies are dug, and most non-TOI items are identified as such and are not identified for digging.

3.8.2 Data Requirements

The dig list, including classification results and excavation results, is analyzed and a ROC curve is prepared.

3.8.3 Success Criteria

The objectives are met if the ROC curve is steep and 70 percent of non-TOIs are below the stop dig threshold and 100 percent of TOI are above the stop-dig threshold.

3.9 OBJECTIVE: CORRECT ANOMALY LOCATION

The modeled location from the cued data accurately depicts the location (laterally and vertically) of the anomaly source.

3.9.1 Metric

The metric is the offset between the inverted anomaly location and the excavated location.

3.9.2 Data Requirements

The dig list x,y coordinates (inversion results) and the dig team's offset between the dig list and recovered locations are compared.

3.9.3 Success Criteria

The objectives are met if 90 percent of the two location total offset is within 25 cm and the depths are within 10 cm.

4.0 SITE DESCRIPTION

RSA-312, Former Range Area for Gate 7 Expansion, is located in the northwestern portion of RSA (**Figure 1-1**). Test Areas 3 and 6 are included in RSA-312. These areas were used during World War II to test munitions produced at RSA. The boundary of RSA-312 encompasses the majority of former RSA-073. RSA-073 was a 9.23-acre field that was used for explosives training and munitions testing as part of historical Area 1 during the 1940s and 1950s.

An 8.5-acre area of the former RSA-073 is included in RSA-312. Current operations at Test Areas 3 and 6 include field testing a variety of sensor and designator systems on ground and aerial platforms under clear and simulated battlefield conditions. No conventional munitions are currently tested or expended on these areas. Additionally, some areas of Test Area 6, north of RSA-312, were used for firing small missiles and rockets.

4.1 SITE SELECTION

Selecting RSA-073 as the subject of a live site demonstration had many advantages:

- DAVS and vegetation clearance had been completed.
- A variety of MEC types were found to be potential TOIs during the historical document review.
- The site presented challenging conditions in terms of a wide range of vegetation density and canopy as seen in **Figure 4-1**.
- CB&I has had a presence at RSA since 1996.
- CB&I had in-place approved procedures and a comprehensive Accident Prevention Plan governing MEC investigations.
- CB&I had available on-site support facilities and UXO personnel.

Figure 4-1 Tree coverage Typical of RSA-073

4.2 SITE HISTORY

Available historical information indicates that RSA-312 was largely undeveloped or was farmland prior to 1941. In mid-1941, the Army began developing the RSA area as a result of World War II. Since the establishment of RSA, the western boundary has essentially remained constant. While numerous range areas were developed in support of testing activities for ordnance manufactured at RSA during World War II, available historical information indicates that the areas within RSA-312 were not used as impact or explosives testing areas.

Areas east of Anderson Road were used for explosives training and munitions testing and has impact areas for 4.2-inch mortars, large caliber projectiles (75-mm to 155-mm), and numerous types of bombs. With the exception of some areas north of RSA-312 and former RSA-073, the majority of the areas west of Anderson Road to the RSA boundary was safety/buffer zones. A review of available historical photographs identified only limited activities occurring in areas west of Anderson Road. RSA-073 is not a known impact area; however, land scarring/craters are visible in RSA-073 in the Light Detection and Ranging data set. The MEC reportedly used in RSA-073 includes: AN-M76 bombs, PT1 (incendiary mixture similar to Goop) filled; M47-type bombs, IM-AE, and napalm filled; M69 bombs, IM-AE filled; 155-mm projectiles, WP and FM filled; 105-mm WP projectiles; 81-mm projectiles, WP and HE filled; 75-mm FM projectiles; 40-mm HE projectiles; and M5 bursters.

The 50.6-acre RSA-312 site (and the approximately 8.5 acres of RSA-073 within RSA-312) is located on RSA property (**Figure 1-1**), west of Anderson Road, along the western boundary of RSA. RSA-312 extends from Interstate 565 along the western RSA boundary to a point south of Martin Road. The sites, as shown on **Figure 1-2**, consist mostly of wooded and limited pasture areas.

4.3 SITE GEOLOGY

Generally, Tuscumbia Limestone (bedrock) and associated overburden residual soil underlie RSA. The rocks underlying RSA are primarily from the Mississippian Age and consist of (in ascending order): Chattanooga Shale, Fort Payne Chert, Tuscumbia Limestone, Monteagle Limestone, Pride Mountain Formation, Hartselle Sandstone, and Bangor Limestone. Dissolution of the Tuscumbia Limestone has formed large caves, caverns, springs, and openings that have caused sinkholes and depressions on the surface. The Chattanooga Shale is approximately 198 feet below ground surface (Malcolm Pirnie, Inc., 2008).

The site ranges from approximately 570 feet above mean sea level near Martin Road to approximately 660 feet above mean sea level in the northwest corner of the site (Malcolm Pirnie, Inc., 2008).

4.3.1 Soil

Soil is typically cherty silt loams and silty clay loams. In northern RSA, the soil correlates well with the bedrock, where approximately 40 to 50 feet of red, sandy clay residual soil overlie limestone and narrow lenses of sandy, poorly drained soil. Residual soil at RSA is derived from limestone and consists of sandy clay, chert, and limestone fragments in a clay matrix. Significant deposits of alluvial and colluvial materials (clays, silts, sands, and gravel) are typically confined to the lowlands at RSA.

4.3.2 Hydrogeology

Groundwater data are available for the RSA-073 section of the munitions response site, where the depth to groundwater ranges from 34 to 50 feet below top of casing. Groundwater flows to the west.

4.4 MUNITIONS CONTAMINATION

Potential MEC at RSA-073 includes: 4.2-inch mortars; AN-M76 bombs, PT1 filled; M47-type bombs, IM-AE and napalm filled; M69 bombs, IM-AE filled; 155-mm projectiles, WP and FM filled; 105-mm WP projectiles; 81-mm projectiles, WP and HE filled; 75-mm FM projectiles; 40-mm HE projectiles; and M5 bursters.

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5.0 TEST DESIGN

The following sections provide information about the project design. Work was conducted in accordance with the Demonstration Plan and its supporting guidance documents.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

Given the wide variety of possible munitions and that the area is considered to have a medium-to-high anomaly density, a goal of CB&I was to demonstrate whether large munitions, such as 4.2-inch mortars at a depth of approximately 90 cm, can be confidently classified in a challenging environment such as this. The task is also made more challenging by the moderately dense vegetation, and noisy site conditions for electromagnetic systems. RSA-073 was surveyed in both dynamic and cued mode for detection and classification.

Dynamic data collection was performed with the TEMTADS integrated with an RTS in man-portable mode along lines spaced nominally at 0.4 meter apart. These data were used for detecting anomalies.

Cued data were collected where the TEMTADS was stationary at each anomaly detected during the dynamic data-collection event. These data were used for classification of each anomaly.

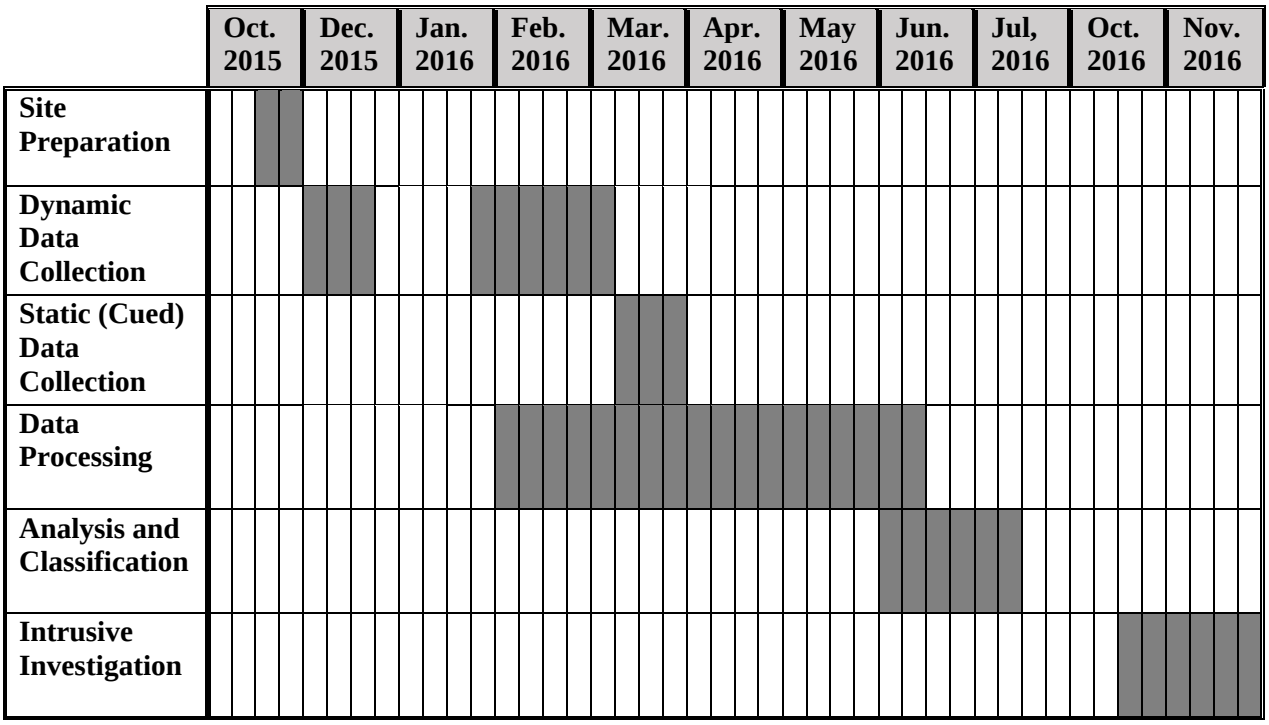
Although the goal was to find 4.2-inch mortars up to depths of 90 cm, CB&I attempted to classify all TOIs correctly and thereby reduce the number of unnecessary digs of non-TOIs. As such, data were analyzed in terms of agreement between classification and excavation results with an evaluation of applicability of the advanced classification technology for use in future treatability studies.

The schedule of work is depicted in **Table 5-1.** The steps for the demonstration were as follows**:**

1. Site Preparation
2. Dynamic Data Collection (detection survey)
3. Static Data Collection (cued survey)
4. Data Processing
5. Analysis and Classification
6. Intrusive Investigation

Field activities and equipment were linked to scheduling for other tasks on site. The TEMTADS unit and geophysical personnel were shared with concurrent work at the Marshall Space Flight Center in late 2015. Intrusive activities at RSA-073 were coordinated to coincide with overall intrusive activities at RSA-312, and as such, the timeline in **Table 5-1** includes the comingled intrusive investigations.

Table 5-1 Schedule



5.2 SITE PREPARATION

Prior to the TEMTADS surveys, the following site preparation activities were performed:

- DAVS.
- Debris, including general metallic debris, was removed.
- Vegetation within the interior of these units was mechanically cleared.
- Control nails and markers located on the previous 100 ft. grid system used for DGM activities by ERT, Inc., and CB&I were verified and reestablished when necessary by a Professional Licensed Surveyor.

Additional removal of surface debris had to be completed prior to dynamic data collection due to the relatively low ground clearance of the TEMTADS unit.

5.2.1 Blind Seeds

CB&I seeded the site using small, medium, and large industry standard objects (ISOs) as well as inert items. Planned seed placement was such that the field crew would encounter roughly one QC seed item per field day during dynamic and cued data collection. Quality assurance (QA) blind seeds were also buried by USAESCH using the same strategy. The seeds were placed at depths to monitor both detection and classification. The seed depths and locations were documented to within 2 cm using an RTS, and the azimuth and inclination were recorded.

All seeds were blind to the data processors. The QC blind seed locations, depths, orientations, and item types were reported to the CB&I QC geophysicist and ESTCP representative. The quality assurance blind seed information was divulged to ESTCP only.

5.3 SYSTEM SPECIFICATION

5.3.1 Antenna Platform

The TEMTADS system is built from PVC and fiberglass, and the receivers are mounted on a wheeled cart. The positioning sensor rests on a five-legged platform above the center of the system. The data-acquisition computer and electronics are mounted in the operator's backpack; it is man-portable. **Figure 5-1** presents a photo of the uncovered TEMTADS coils and receiver cubes.

Figure 5-1 TEMTADS Transmitter Coils and Receiver Cubes

5.3.2 Signals and Timing

TEMTADS data are collected in time blocks with a fixed number of transmitter cycles where the period and the repeat factor are operator-selected. The TEMTADS also averages an operator-specified number of stacks, and the data are saved.

The decay transients that are received during the off-times are stacked (averaged) and marked as positive and negative half cycles. The decays are stacked, and the decays in that block are averaged with the other acquisition blocks. The data are saved as a data point.

The TEMTADS records RTS positions while the electromagnetic data are being collected. The RTS streams pseudo-National Marine Electronics Association data to the TEMTADS, similar to a GPS. Transmitter switching and receiver sampling is controlled by hardware that is programmable. In dynamic mode, data collection of a new data point is concurrent with completion of the previous data point, therefore yielding continuous data until the operator stops the data collection. All continuous data are stored in a single output file. In cued mode, the TEMTADS collects a single data point and then terminates acquisition. The data are stored as a single data point in the output data file.

Decay data are collected at a rate of 500 kilohertz after turn-off of the excitation pulse for up to 25 ms, as indicated with the *HoldOff* parameter. The raw decay measurements are grouped into logarithmically spaced time gates with center times ranging from 25 µs to 24.35 ms with proportional widths. Responses within a specific time gate are averaged and become the value of the signal for that time gate. The widths of the gates are determined by the *GateWidth* parameter and are specified as a percentage, for example, the width of a gate at 600 µs would be 60 µs with a gate width of 10 percent.

5.4 CALIBRATION ACTIVITIES

To ensure the proper operation of all instrumentation during field activities, CB&I established a routine of calibration activities that was performed daily when weather permitted.

5.4.1 Instrument Verification Strip and Test Stand

A relatively metal-free area near the demonstration grids was selected to house an IVS used for daily QC of the TEMTADS deployment configuration. In lieu of a training pit, a test stand was established to collect cued data on items expected in the grids that were not in the current signature library used for matching during data analysis. The stand was series of sawhorses, which ensured the stability of the TEMTADS, and the test items could be placed at various depths and orientations relative to the sensor. Details of the IVS are provided in **Table 5-2** and the IVS item locations and adjacent dynamic background line between survey nails "BG2 W" and "BG2 E" are presented in **Figure 5-2**.

Table 5-2 Details of the Instrument Verification Strip

Item ID	Item	Northing (UTM m)	Easting (UTM m)	Burial Depth (cm)	Orientation
IVS-1	MEDIUM ISO V	3833902.460	526427.7978	30	V
IVS-2	SMALL ISO V	3833902.377	526432.1479	6	V
IVS-3	4.2´´ projectile H	3833902.207	526436.8893	60	H (In-line with direction of travel)
IVS-4	SMALL ISO H	3833901.971	526442.8170	4	H (In-line with direction of travel)

cm – centimeter
H – horizontal
ID – identification
ISO – industry standard object
IVS – instrument verification strip
m – meter
UTM – Universal Transverse Mercator
V – vertical

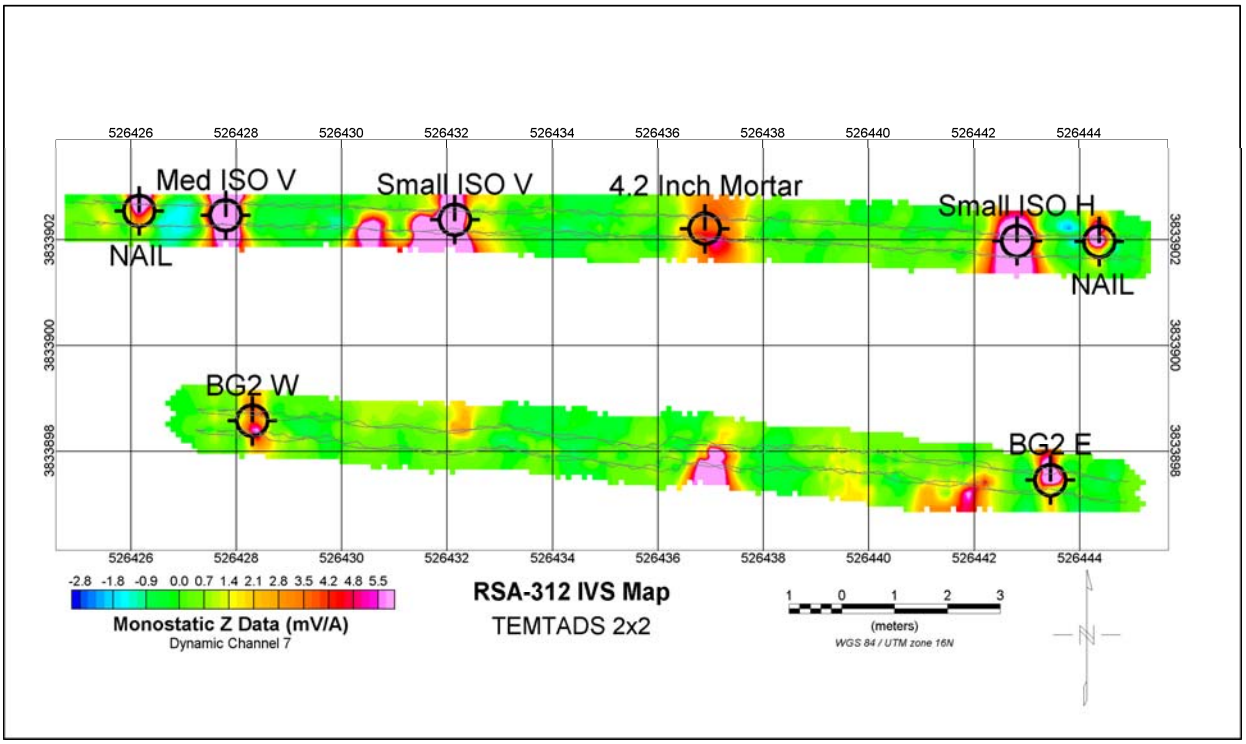


Figure 5-2 IVS Location Map

5.4.2 IVS ACTIVITIES

The IVS was used for daily function checks of the TEMTADS and RTS. The IVS was surveyed prior to the first data-collection event and after the completion of data collection each day. The recorded sensor response and detection location was compared to the expected sensor response and known location for each ISO to verify equipment functionality.

The dynamic IVS activity procedures were as follows:

1. Collect static RTS data at a control point established near the IVS to confirm accuracy.
2. Perform internal TEMTADS tests.
3. Acquire static background data at the designated "background" test location (a metal-free area near the IVS), and perform a sensor function test over this background.
4. Set acquisition parameters for dynamic (dynamic identification [ID]) data acquisition.
5. Traverse the IVS and adjacent dynamic background line in two opposing line directions.

The cued IVS activity procedures were as follows.

1. Collect static RTS data at a control point established near the IVS to confirm accuracy.
2. Perform internal TEMTADS tests.
3. Acquire static background data at the designated "background" test location (a metal-free area near the IVS), and perform a sensor function test over this background.

4. Set acquisition parameters for static (cued ID) data acquisition.
5. Acquire static data for each of the items in the IVS.

The IVS surveys provide all the data required to perform QC checks that document that the instrument is functioning correctly. The resulting data were used to establish the long-term stability of the instrument response.

5.4.3 Test Stand

A test stand was established prior to cued and dynamic data collection over the background location used at the IVS shown in **Figure 5-3**. A series of items including a MK83 grenade, 81mm mortar, and a 4.2-inch mortar were placed at distances up to 2.6 feet below the TEMTADS, and cued measurements were recorded. These measurements provided additional polarizability signatures for the matching library.

Figure 5-3 TEMTADS on Test Stand

5.5 DATA COLLECTION PROCEDURES

Data collection procedures are described below.

5.5.1 Scale

CB&I collected approximately 8.21 acres of dynamic data following the 100-foot by 100-foot grids system at the site as shown in **Figure 5-4**.

A total of 1,178 anomalies from the larger set of targets identified in the dynamic data were investigated using the TEMTADS in cued mode. These targets represent a subset of the 14,873 anomalies detected above the 1.4 millivolts per ampere (mV/A) threshold, as time and budget constraints meant availability of the TEMTADS equipment was limited until the end of March 2016.

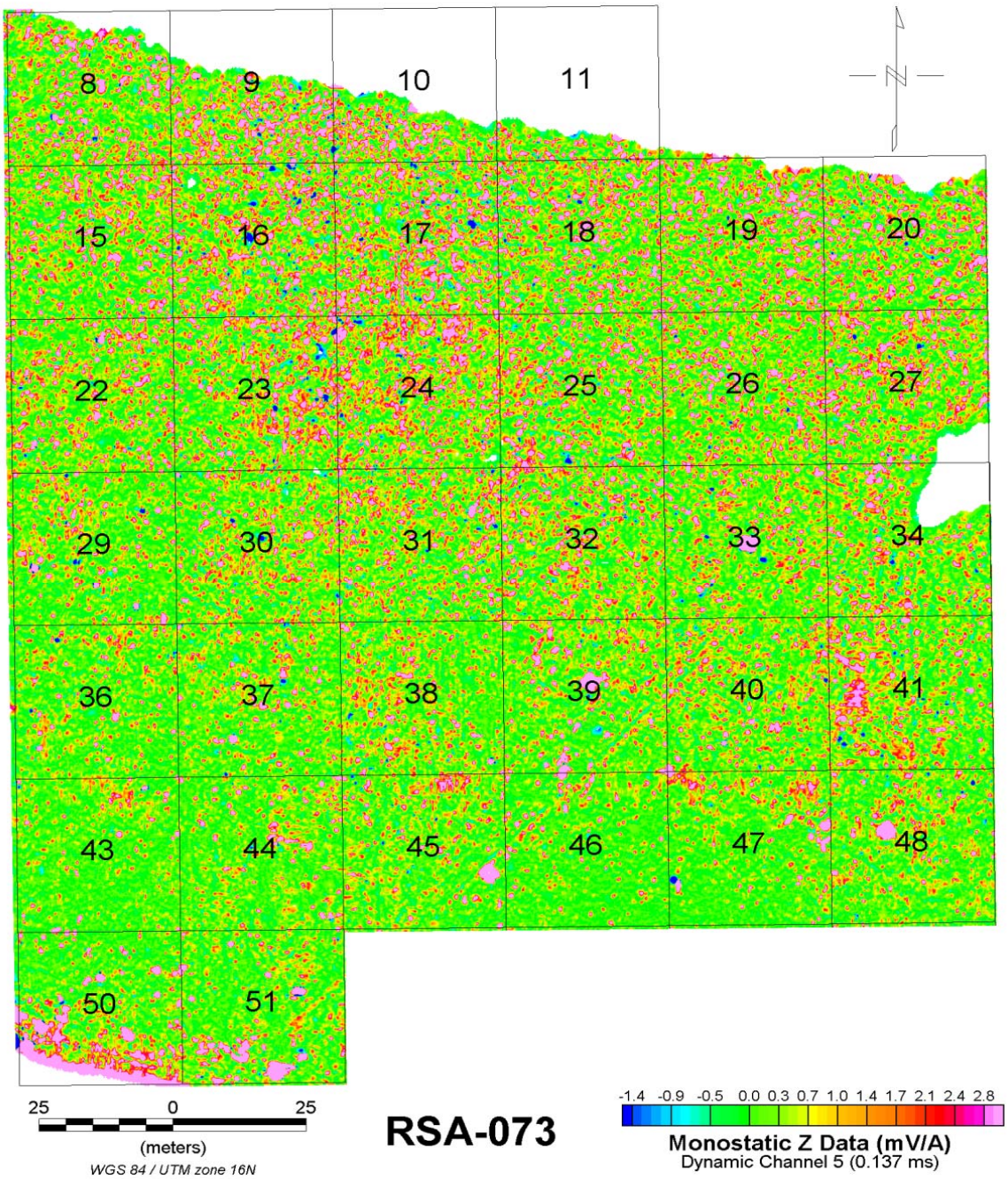


Figure 5-4 TEMTADS Dynamic Data Collected over the Accessible Areas of RSA-073

5.5.2 Sample Density

Dynamic surveying activities consisted of complete coverage of accessible areas in the designated survey area. Data were collected along parallel transects with 0.4 meter nominal line spacing with some deviation from a straight line path due to obstructions. Sample rate and survey speed were slow enough to ensure over 90 percent of down-line spacing was less than 15 cm and 100 percent less than 20 cm.

The cued mode data collection consisted of surveying static data over a list of anomalies identified from the dynamic survey. Cued data were collected over each identified anomaly, with measurements repeated as necessary due to offsets of the sensor relative to the anomaly source or other data quality issues.

5.5.3 Quality Control

The measurement quality objectives (MQO) along with the testing frequencies, acceptance criteria, and failure response are presented in **Table 5-3**. A discussion of key MQOs and exceptions follows the table below.

Table 5-3 Quality Metrics Summary

Measurement Quality Objective	Frequency	Acceptance Criteria	Failure Criteria	Results
Verify correct assembly	Once following assembly	As specified in manufacturer's manual	Make necessary adjustments, and re-verify	Assembly of the TEMTADS unit was in accordance with manual and verified by NRL staff
Initial IVS background measurement (five background measurements: one centered at the flag and one each offset 40 cm in each cardinal direction)	Once during initial system IVS test	All decay amplitudes lower than detection threshold (threshold dependent upon soil response). Match metric ≥ 0.9 for each of the five sets of inverted polarizabilities if test item is used.	Reject/replace background Location	The initial background measurement was lower than the detection threshold. Match metrics ≥ 0.9 were obtained for the 5-point background test.
Initial derived polarizabilities accuracy (IVS)	Once during initial system IVS test	Library match metric ≥ 0.9 for each set of inverted polarizabilities	Recollect data. Change baseline fit metric if it is deemed that site-specific conditions are the cause after verification using test pit data. Add to the match library as needed.	The initial library match metric was greater than 0.9 for IVS items 2, 3, and 4. The initial library match for item 1 was 0.79, while ongoing matches were always above 0.87 once this was added to the library.
Derived target position accuracy (IVS)	Once during initial system IVS test	All IVS item fit locations within 0.25 meter	Verify RTS readings at a benchmark and re-surveyed	IVS items 1, 2, and 4 were within 0.25 meters of ground truth for all cued measurements. Item 3 was outside of the 0.25 meter metric during all cued tests.

Table 5-3 Quality Metrics Summary (Continued)

Measurement Quality Objective	Frequency	Acceptance Criteria	Failure Criteria	Results
Ongoing IVS background measurements	Twice daily as part of IVS testing	All decay amplitudes lower than detection threshold	Reject background measurement and re-measure. If weather or site environment has changed, document the change and alert data analyst and QC geophysicist. In the case of equipment failure, reject IVS data and survey data (from where instrument begins to fail).	All decay amplitudes of background measurements were verified to be below the detection threshold.
Ongoing derived polarizabilities precision (IVS)	Twice daily as part of IVS testing	Library match metric ≥ 0.9 to the initial IVS measurements for each set of inverted polarizabilites	Re-test; verify polarizability of QC seed items.	Ongoing match metrics for items 2, 3, and 4 exceed the 0.9 metric during all tests. The ongoing library match metric for item 1 failed to meet the 0.9 metric during 5 out of 112 tests, being at least 0.87 during those.
Ongoing derived target position precision	Twice daily as part of IVS testing	All IVS item fit locations within 0.25 meter of ground truth locations.	Verify RTS QC tests; verify the locations of QC seeds.	IVS items 1, 2, and 4 were within 0.25 meters of ground truth for all cued measurements. Item 3 was outside of the 0.25 meter metric during all cued tests.
Initial measurement of production area background locations (five background measurements: one centered at the flag and one each offset)	Once per background location	All decay amplitudes lower than project threshold (threshold dependent upon soil response). Match metric ≥ 0.9 for each of the five sets of inverted polarizabilities if test item is used	Reject background location and find alternate.	Background locations that had elevated responses were removed, as were those that failed the 5-point tests.
Ongoing production area background measurements	Background data collected nominally every 2 hours during production (minimum)	All decay amplitudes lower than project threshold with qualitative agreement with initial measurements	Reject background measurement and recollect.	Backgrounds were collected every at least every two hours during cued data collection. Backgrounds with elevated thresholds were removed.

Table 5-3 Quality Metrics Summary (Continued)

Measurement Quality Objective	Frequency	Acceptance Criteria	Failure Criteria	Results
Confirm all background measurements are valid	Evaluated for each background measurement	All decay amplitudes lower than project threshold with qualitative agreement with initial measurements	Reject background measurement and remove from active background measurements.	Of 126 cued background location measurements, 35 were discarded for use in leveling adjacent cued data.
Confirm inversion models support classification	Evaluated for all models derived from a measurement (i.e., single-item and multi-item models)	Derived model response must fit the observed data with a fit coherence ≥ 0.8	Review all available information. Make decision.	Roughly 4% of models had a fit coherence < 0.8. These targets were classified into categories 0 and 3 or were associated with targets matched to fuze components.
Confirm inversion model supports classification	Evaluated for derived targets	Fit location estimate of item ≤ 0.4 meter from center of sensor	If no target within 0.4 meter radius using multi-solver inversion, classify as "inconclusive."	All targets with a fit location more than 0.4 m from the center of the sensor had a classification of inconclusive.
Confirm inversion model supports classification	Evaluated for all seeds	100% of predicted seed (x,y) ≤ 0.4 meter and (z) ≤ 0.1 meter positions from known position (x, y, z).	Evaluate seed locations.	95% of seeds with cued measurements and positions recorded during excavation were within 0.4 m. 85% of seeds were within 0.1 m of their predicted depth.
Confirm reacquisition GPS precision	Daily	Benchmark positions repeatable to within 10 cm	Make adjustments and re-verify.	Check shots were performed daily at the IVS pre- and post-survey. All were within 5 cm of the benchmark.
Confirm derived features match ground truth	Evaluated for all recovered items	100% of recovered (excluding inconclusive category) item positions ≤ 0.25 meter from predicted position (x, y).	Verify RTS tests.	89.52% of recovered items were within 0.25 meters of the predicted position.
Confirm derived features match ground truth	Evaluated for all recovered items	100% of recovered object shape estimates (excluding inconclusive category) qualitatively match predicted shape.	Continue excavation based on items recovered.	Shape and size, as inferred from the modeled polarizabilities were evaluated qualitatively for each recovered item.
Classification validation	Evaluated for all recovered items	100% of predicted non-TOI are correctly characterized	Continue excavation based on items recovered.	All digs in category 3 were non-TOIs except for one target, which was a portion of an M50-X.

While the initial library match metric was greater than 0.9 for IVS items 2, 3, and 4, the initial library match for item 1 was 0.79. The low initial match for the IVS item 1 appears to from a sensitivity to the background correction being applied to it. When the background correction is made from alternative background locations in the RSA-073 survey grids, initial matches to a medium ISO are obtained above the 0.9 match metric objective. Ongoing matches to this initial measurement's modeled polarizabilities were always above 0.87 once this was added to the library, and generally above 0.9.

IVS items 1, 2, and 4 were within 0.25 meters of ground truth for all cued measurements, but item 3 was outside of the 0.25 meter metric during all cued tests. Given the very consistent location of this item's inverted position, and the good initial and ongoing library matches obtained, it is a distinct possibility that the center of mass for this horizontal object was not properly recorded.

For each grid with cued targets, five potential background locations were given to the field team. This high density of background locations was deemed prudent given the difficulty experienced obtaining suitable background measurements in more saturated areas of the Redstone installation. For the sake of expediency with RTS setups, the field team chose to use as few as two or three of these backgrounds. Additionally, the close nature of backgrounds to targets in adjacent grids meant that background measurements within a reasonable proximity and time-frame were suitable for leveling the cued measurements. Of 126 cued background location measurements, 35 were discarded for use in leveling adjacent cued data. These were assessed based on difference statistics calculated by background QC tools in UXAnalyze and qualitative analysis of the background decay data.

As 89.52 percent of recovered targets were within 0.25 meters of the predicted position, the 100 percent MQO was not met. Generally, those that fell outside were non-TOIs with intrusive investigations yielding frag or other debris.

All of the category 3 digs were non-TOIs except for target 440001, which was a portion of an M50-X and had polarizabilities that could not be extracted properly resulting in an inconclusive match metric, which may have been better placed in category 0. The same item was examined for the adjacent target 440002, placing it outside of the non-TOI classification in category 2.

Additional Tests

Sensor function tests were performed by placing a small ISO in a prescribed socket directly above the center of the TEMTADS receiver array. The response amplitude of each TxRx combination is evaluated against a reference response. Sensor function tests were performed during each IVS test, and during cued data collection in the study grids, with results shown in **Figure 5-5**, all being less than 20 percent from the reference responses.

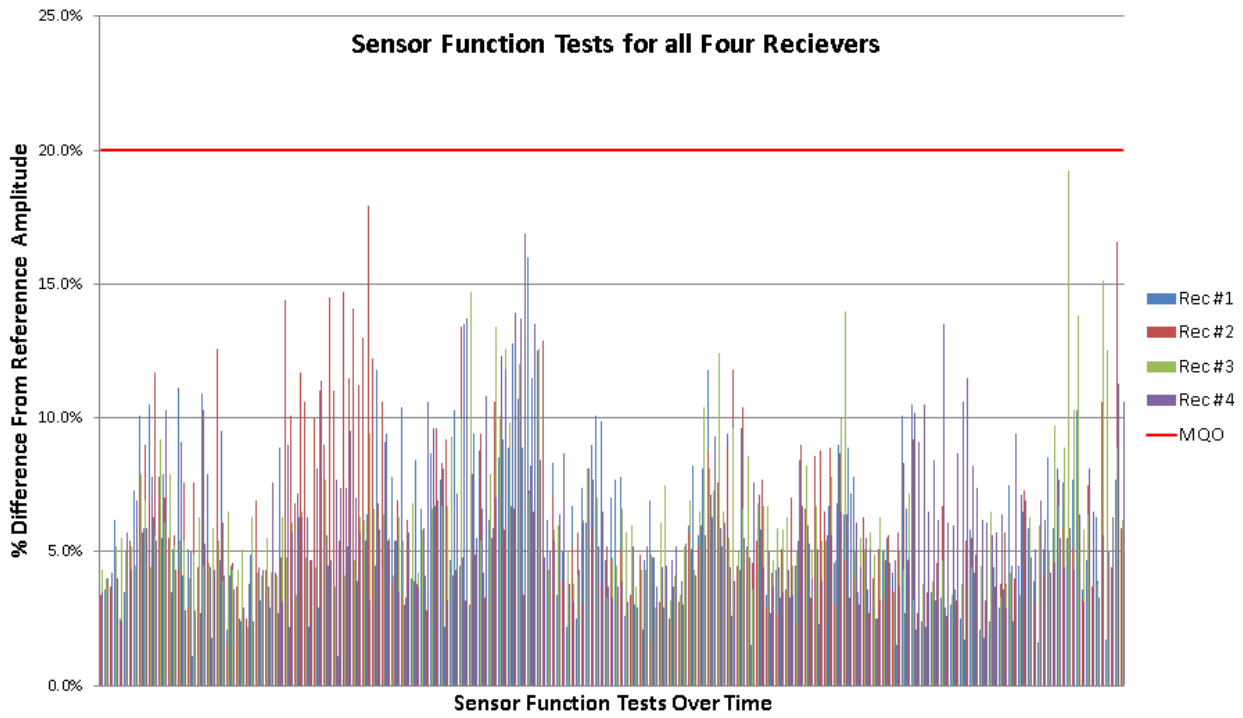


Figure 5-5 Sensor Function Test Results for Each of the Four TEMTADS Receivers

5.5.4 Data Handling

The raw data for the TEMTADS were copied from the "raw" folder for processing so that the original files were never compromised and the sequence of processing events could be reconstructed if necessary. The raw dynamic binary .TEM files were converted to .CSV files and were processed in UX-Analyze. Final TEMTADS data were archived in a Geosoft-compatible format.

The TEMTADS acquisition software has a fixed convention for assigning a unique name to each file. CB&I used "RSA" as the prefix. The acquisition software appended a five-character number to the filename prefix to form a unique name for the file (e.g., RSA_021116_GRID_000001). The numbering during cued data collection was sequential. During cued data collection the file names included the date, grid, and Target ID (e.g., RSA_031916_grid23_230022)

Dynamic data were renamed based on the date of data collection, and static data were renamed based on the ID determined for each target picked in the dynamic survey. If repeated measurements during the cued investigation of a single anomaly were required, the unique Target ID continued to be used. A letter indicating the number of recollects was appended to the filename, after the Target ID (e.g., RSA_031916_grid23_230022a).

Each data acquisition file name was digitally documented using a data-tracking spreadsheet. Other information recorded included the responsible geophysical crew, the grid(s) that the file covers, and the data processor.

The data were uploaded to a project Microsoft® SharePoint site and secure file transfer protocol (SFTP) site daily so that ESTCP had easy access to the most current data. A representative example of the folder structure follows:

ESTCP/Field
- Dynamic Data
  - 2016 03 09
- Static Data
  - 2015 11 17
  - /Processing
    - GRID_Data (dynamic)
    - Cued_Processing

5.6 VALIDATION

A subset of 221 targets was intrusively investigated during corresponding activities throughout the entire RSA-312 site. Each item encountered was identified and photographed. For items recovered during the intrusive investigation of a target, depth was measured, and its location determined using cm-level RTS. Recovered items were removed for disposal when possible. ESTCP's Intrusive Investigation Data Collection Instructions were followed in accordance with Appendix E of the ESTCP demonstration plan (CB&I, 2015).

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6.0 DATA ANALYSIS AND PRODUCTS

The following sections outline the data analysis.

6.1 PREPROCESSING

Raw data were collected and stored as .TEM files. Pre-processing of the raw .TEM files includes exporting the resulting data to a .CSV file using the ConvertTEMTADS_RTS v3.1.0 application for import into UX-Analyze, and converting from the geographic coordinate system to the Universal Transverse Mercator (UTM) Zone 16N coordinate system used for processing (for each receiver). The cued data collection software, when used with the Trimble RTS units, did not output geographic latitude and longitude values. Instead the UTM Zone 16N values were used for positioning. Because these were not recognized by UX-Analyze in the version at the time of processing, custom resource files provided by Acorn were used for processing of UTM coordinates. The use of Acorn's custom resource files were only necessary for cued data due to the differences between the raw data file structure of dynamic and cued files and the conversion software used to process each.

Given the tree density of the test area, optical shadows between RTS and prism were minimized as much as possible, but unavoidable. Positioning information was interpolated linearly between valid positions for detection survey data.

Since the TEMTADS is a multi-static sensor, data from each component of each receiver cube must be leveled independently. The UCEdrift non-linear filter in Geosoft's Oasis Montaj program was used to level the data with a low of 20, high of 0, and window of 10.

6.2 TARGET SELECTION

Target picking was performed on gridded, dynamic TEMTADS monostatic data in the z (vertical) direction. The detection threshold was set at 1.4 mV/A on channel 5 (0.137 ms), which corresponded to the modeled response of a horizontal 4.2-inch mortar at depth of 3 feet. The availability of the TEMTADS unit and budgetary constraints limited the number of targets that could be interrogated in cued mode to less than the total number of targets detected. A secondary threshold was applied at 3.25 mV/A on channel 5, approximately five times the root mean squared (RMS) background noise level. This resulted in an anomaly list for cued interrogation of targets with sufficiently high signal allowing for consistent and reliable inversions. For the majority of full 100 feet by 100 feet grid, 47 targets above the 3.25 mV/A threshold were randomly selected by the data processors, and the QC and QA geophysicists selected additional anomalies potentially as low as 1.4 mV/A threshold for a total of approximately 50 targets per grid as summarized in **Table 6-1**. Grid 43 was an exception to this process where 82 targets were investigated in cued mode while the strategy used in the rest of the grids was being finalized. Target counts by grid are summarized in **Table 6-1**.

Table 6-1 Anomaly Tallies in ESTCP Cued Survey Grids

Grid (Laid out for ESTCP project)	Number of 2x2 Targets above 1.4 mV/A on Ch5	Number of 2x2 Targets Above 3.25 mV/A on Ch5	Number of 2x2 Targets With Cued Measurement
Grid15	549	261	52
Grid17	754	416	53
Grid22	531	225	50
Grid23	678	289	51
Grid24	776	362	53
Grid25	608	276	53
Grid26	589	276	53
Grid29	410	127	51
Grid30	547	175	51
Grid31	595	244	52
Grid32	594	236	52
Grid34	456	176	53
Grid35	208	79	49
Grid36	321	105	53
Grid37	291	94	53
Grid38	405	125	53
Grid39	381	142	53
Grid40	484	157	53
Grid43	213	66	82
Grid44	261	95	52
Grid45	329	100	53
Grid46	199	72	53

Ch5 – channel 5
mV/A – milliVolts per Ampere

Subsurface investigations of TEMTADS anomalies in RSA-073 were performed in conjunction with subsurface investigations for the RSA-312 production work.

Table 6-2 below summarizes the rationale for the selection of excavation locations. Additionally, the subsurface investigation of a subset of TEMTADS anomalies had the following benefits for the RSA-073 site characterization:

- The RTS position precision is on the order of cm instead of feet;
- The necessity of an IMU to properly orient and locate the instrument during advanced classification efforts, means that minor terrain variations are included in the position information;

- The resolution of 2x2 detection data is inherently higher given the multiple, smaller receiver coils, and their geometry within the sensor;
- Anomalies that have been cued with the 2x2, have a modeled location and depth not possible with EM61 data;
- Anomalies with cued 2x2 measurements also have size estimates based inverted polarizabilities, and their matches to library items; and
- Similar anomalies cluster together in the size vs. decay feature space, allowing for the characterization of all items in the cluster by digging a few.

Table 6-2 Targets Selected for Excavation

# of Anomalies	Selection Criteria	Additional Comments
119	Anomalies where the modeled location from the TEMTADS measurement is within 0.5 m of the picked location of an EM61 anomaly.	69 of these are currently ranked as TOI, 18 of these are ranked as likely clutter, and 32 were associated with hypergeometric targets picked from the EM61 survey. The EM61 targets were selected to be a statistically significant portion of all of the existing EM61 targets following a hypergeometric distribution, and were slated for intrusive investigation as part of work at RSA-312.
16	Anomalies with a TOI match other than a fuze or Aluminum rifle grenade, and not within 0.5 m of an EM61 anomaly pick.	
7	Anomalies that are categorized as "can't analyze" during the ranking process.	
24	Anomalies that have a range of predicted sizes.	The goal is to characterize the site in terms of item size, something not accurate with EM61 data.
32	Anomalies that were positioned within the optical shadow of trees with respect to the RTS during the dynamic detection survey.	The goal is to evaluate the performance of the RTS in these site conditions.
23	QC Targets	Quality Control Check
221	**TOTAL**	

6.3 PARAMETER ESTIMATION

Cued TEMTADS records for each of the detected anomalies were imported into UX-Analyze to perform inversions generating information on the x-y-z location and polarizabilities. Both single and multi-target models were matched during the inversion process. The analyst reviewed 1) polarizability profiles for each record in conjunction with the amplitude and spatial attributes, 2) inverted model fit statistics (signal to noise ratios, general model uncertainty, fit to library models of recovered polarizability), and 3) predicted depth for each model fit. The library matching of the TOI polarizability curves from the library reference items were superimposed on the polarizability profile of each TEMTADS record. This allowed direct comparison of the similarity of the polarizabilities. A decay-size feature plot was used to evaluate each model's attributes, and make comparisons to the entire dataset and library of reference items.

Each model and inversion result was passed or failed by the data analyst. Notes regarding whether the anomaly is a suspected TOI, based on the library of reference items or an elongated, UXO-like object, were made as necessary, in order to facilitate final ranking during dig-list development. **Figure 6-1** presents the progression of an anomaly from dynamic detection through intrusive investigation.

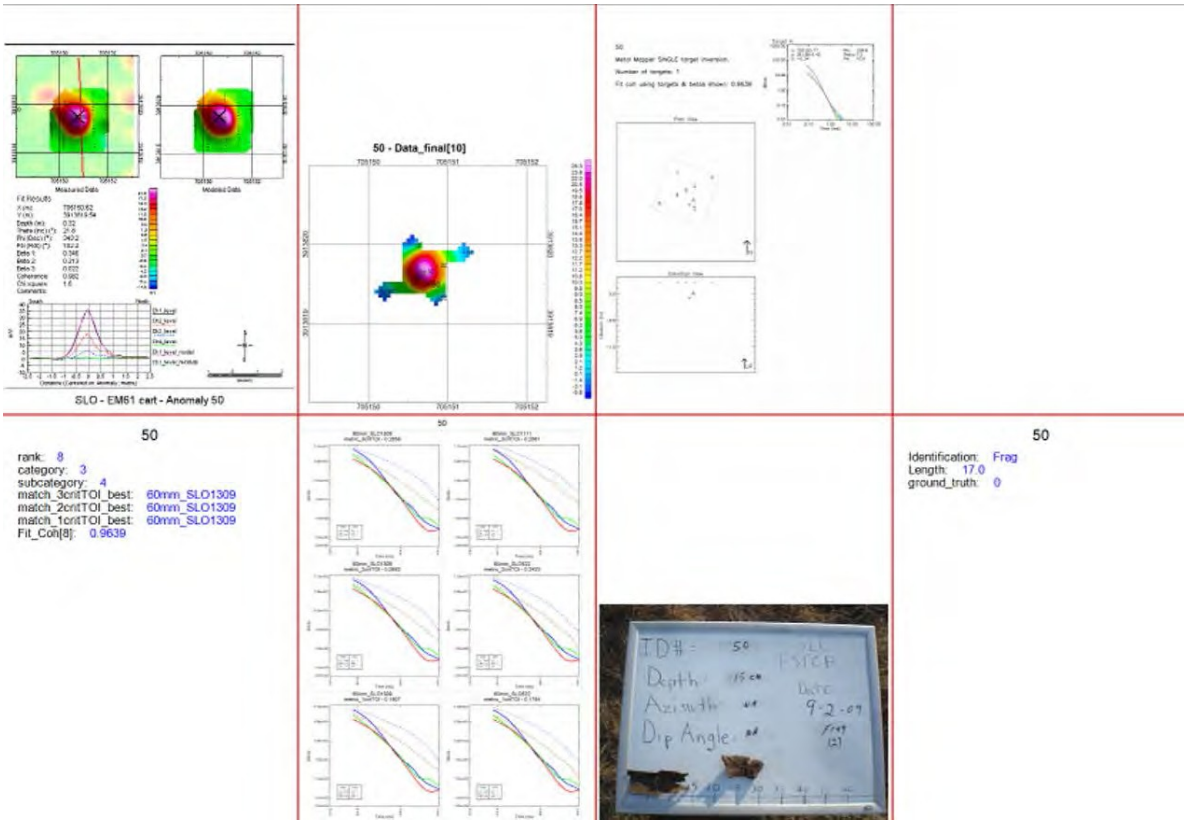

Figure 6-1 Dig List Development

6.4 TRAINING

Training digs were not used as part of this ESTCP project, and instead a single dig list was developed.

The models passed by the analyst from the inversion process were displayed on a feature plot with the decay on the y-axis and relative size on the x-axis along with the library reference items. Anomalies that clustered close to the library reference items were evaluated further in terms of the similarity of their polarizabilities to those of the known TOI. During the analysis and evaluation process, other clusters (or populations) of anomalies were identified, which exhibit UXO-like polarizabilities, signal amplitude, and decay properties. These typically fell into three categories: 1) large clusters with "subclusters" of smaller relative sizes than library reference items, variable decay rates, and UXO-like polarizabilities, 2) relative size larger than a small ISO and smaller than a 57 mm with UXO-like polarizabilities and decay properties, and 3) non-clustered but having interesting combinations of polarizability, decay, or relative size characteristics. These would be passed on for training data under production circumstances.

6.5 CLASSIFICATION

Initial dig-list development used Geosoft's UX-Analyze tool, which is designed to automate the ranking of the dig list. Using this tool, the analyst was able to interactively prioritize anomalies using various parameters such as polarization plots, decay, relative size, analyst notes (e.g., "TOI-like"), and other related attributes. CB&I used the polarization plot compared to the library of reference items and analyst notes (e.g., "TOI-like") as the primary attributes to refine the dig list.

The polarization curves developed for each target, including any single-object-only results and secondary multiple-object results, were compared to a library of known polarization curves compiled using published and project-specific test stand data. The items in the comparison library were limited to items larger than 20 mm as there is no history of 20 mm munitions being used at the site. By removing these small items from the match library, CB&I can minimize the unnecessary digs of small MD. Initial comparisons between the measured targets and the library data were performed using all three primary polarizabilities. If a curve for the primary axis of polarization ($\beta 1$) cannot be identified, the target will either be left for ranking according to the decision statistic developed for the project, or for those targets without an identifiable $\beta 1$ curve, classified as "can't analyze."

Targets with results not necessarily deemed usable on the first pass include those for which one or more non-$\beta 1$ curves appear to be poor data for any reason, or targets that appear to be "TOI-like" but do not have a particularly good match to any of the library objects. "TOI-like" is defined as an object with relatively equal (i.e., symmetric) secondary axes of polarizability ($\beta 2$ and $\beta 3$) for which the magnitude of $\beta 1$ is not less than $\beta 2$ and $\beta 3$. It may be that targets with these characteristics are examples of ordnance not expected at the site and, therefore, not in the comparison library.

The result of this classification analysis was a prioritized dig list (**Table 6-3**).

Table 6-3 Format for Prioritized Anomaly Lists

Target ID:	Category: -1 = Training Set 0 = Can't Extract Reliable Parameters 1 = Likely TOI 2 = Can't Decide	Dig Decision: 1 = Dig 0 = Don't Dig	TOI Size Band: (diameter in mm) 1 = diameter < 50 mm 2 = 50 < diameter < 100 3 = diameter > 100 mm (Leave blank for Dig Decision = 0)
RSA-021	-1	1	3
RSA-347	1	1	3
RSA-145	1	1	2
RSA-001	2	1	2
RSA-298	3	0	3
RSA-103	3	0	2

6.6 DATA PRODUCT SPECIFICATION

The following data were collected as part of the RSA-073 demonstration:

Background Data: Raw and pre-processed background data files were provided along with their locations on the CB&I Federal Services SFTP site. The background files were pre-processed in the same manner as online data with the exception of performing a background correction. Information correlating background files with cued data files is contained within the Geosoft project files. Background files were removed from the processing workflow.

Dynamic and Cued Data: Raw and pre-processed data are provided. The pre-processed data has coordinates converted to UTM Zone 16N and corrected for pitch, roll and yaw.

Dynamic and Cued Inverted Data: Geosoft-compatible files containing the inverted and pre-classified data were provided on the CB&I Federal Services SFTP site. The following are included in this deliverable:

- **Dynamic Data:** All processed data used for anomaly detection.
- **Cued Data:** All leveled and modeled cued target data used for polarizability matching with the item library.

Initial Anomaly List: A list of all anomalies detected above threshold in the dynamic data.

Final Classification Dig List: The anomaly list prioritized and all anomalies classified.

Intrusive Investigation Results: Photos and field notes from the intrusive investigation.

7.0 PERFORMANCE ASSESSMENT

The performance objectives of this study are summarized in **Table 7-1**. The objective and the associated metric, data-collection events, and success criteria are also presented. A description of each follows the table.

Table 7-1 Performance Objectives Evaluation

Performance Objective	Metric	Data Required	Success Criteria	Results
Data Collection Objectives				
IVS repeatability	Location and detection amplitudes are repeatable	Dynamic and cued IVS data	Dynamic: Detection amplitudes are within 25%. Locations are within 0.25 meter. Cued: Library match to initial polarizabilities metric ≥ 0.90 for each set of three inverted polarizabilities. All IVS item fit locations within 0.25 meter of ground truth locations.	During dynamic tests performed at the IVS, all detection amplitudes were within 25% of the average of the first five tests for each of the four items. More than 99% of IVS item locations were within 0.25 meters, with seven outliers. Initial Matches over 0.9 were obtained for items 2, 3, and 4. Item 1 was well below this threshold, but ongoing matches based on its addition to the polarizability library, resulted in matches above 0.87. Modeled locations of IVS items 1, 2, and 4 were within 0.25 meters of ground truth for all cued measurements. Item 3 was outside of the 0.25 meter metric during all cued tests.
Dynamic data full- coverage survey	Across-track line separation Along-line data separation	Dynamic data	90% across-track separation is within 0.5 meter. 100% are within 0.7 meter. 95% along-line data separation is within 15 cm. 100% are within 20 cm. Metrics exclude obstructed areas.	More than 99% of the dynamic data had an across track separation within 0.5 meters, and 100% were within 0.7 meters. Along-line data separation was within 15 cm for 98.8% of dynamic data, and within 20 cm for more than 99.9% of dynamic data.
TOI detection	Detection of seed items	Dynamic data	100% of seed items detected.	12 of 13 QC seeds were detected during the dynamic survey.
Cued data location	Distance between cued location setup and the inverted location	Cued data	Locations within 40 cm.	22 targets had inverted locations outside of 40 cm from the center of the TEMTADS. All were placed in category 0.

Table 7-1 Performance Objectives Evaluation (Continued)

Performance Objective	Metric	Data Required	Success Criteria	Results
Data Analysis Objectives				
Correctly classify TOIs	Identify TOI and seed items	Cued data and excavation results	100% of seed items correctly classified. Correctly classify 100% of TOI.	Of 28 blind seeds, 20 were correctly identified as TOIs, 4 as training digs, and 4 as "can't decide". An additional 26 digs resulted in TOI. Nineteen of these were classified as TOI and the remaining 7 were classified as "can't decide".
Correctly classify non-TOIs	Eliminate false alarms	Cued data and excavation results	70% of non-TOI correctly classified.	70.12% of non-TOIs were correctly classified.
Minimize "can't analyze" anomalies	High quality cued data	Cued data	Less than 5% "can't analyze" anomalies.	3.06% of cued data measurements resulted in a "can't analyze" categorization.
Correctly place the stop-dig threshold	TOIs above stop-dig threshold	Prioritized dig sheet and excavation results	No TOI below threshold. Minimize non-TOI digs above threshold.	Only one TOI-like section of an M50-X was below the stop dig threshold. This target was shared with another measurement that placed it above the stop-dig point.
Correct anomaly locations	Anomaly locations on dig list are accurate.	Detection, inversion and excavated locations	Detected location and inversion location are within 40 cm. Excavated location is within 25 cm of inversion location.	94.98% of the fit locations of all cued targets were within 40 cm of the detection location. 89.52% of measured horizontal dig locations were within 25 cm of the predicted location. 82.38% of measured dig depths were within 10 cm predicted depth.

7.1 OBJECTIVE: INSTRUMENT VERIFICATION STRIP REPEATABILITY

The effectiveness of the technology for detection and classification of munitions is dependent on high-fidelity data that are defensible and repeatable.

7.1.1 Metrics

TEMTADS settings and survey parameters are used such that consistent detection and location of IVS seed items are realized.

7.1.2 Data Requirements

Dynamic and cued data are collected at the IVS before and after each day's production surveying. Detection data are processed and then compared for repeatable amplitudes and location control. Cued data polarizability curves are matched to the library items and to previous results.

7.1.3 Success Criteria

The objectives are met if detection amplitudes are within ± 25 percent, and interpreted locations are within 0.25 meter of the ground truth location of the seed items. The objectives are met for cued surveys if library match to polarizabilities metric ≥ 0.90 and are located within 0.25 meter of ground truth locations.

7.1.4 Results

During dynamic tests performed at the IVS, all detection amplitudes were within 25 percent of the average response of the first five tests for each of the four items. More than 99 percent of IVS item locations were within 0.25 meters, with seven outliers.

Initial matches over 0.9 were obtained for items 2, 3, and 4. Item 1 was well below this threshold, but ongoing matches based on its addition to the polarizability library, were all above 0.87. The initial match for item 1, the medium ISO, was 0.79. As mentioned in Section 5, the low initial match for the IVS item 1 appears to be the result of a sensitivity to its background correction.

The derived positions of IVS items 1, 2, and 4 were within 0.25 meters of ground truth for all cued measurements. Item 3 was outside of the 0.25 meter metric during all cued tests. Given that item 3 is a horizontal 4.2-inch mortar, and the good repeatability of the inverted position, it is a possibility that the ground truth measurement was not made at the geometric center of the object. Additionally, the ongoing matches relative to the initial IVS tests for item 3 are in good agreement, and offsets between the inverted and ground truth locations are consistent over time.

7.2 OBJECTIVE: DYNAMIC DATA FULL-COVERAGE SURVEY

The detection of all munitions depends on ample detection survey coverage. The coverage for both across-track line separation and along-line data separation are included in coverage.

7.2.1 Metric

TEMTADS settings and survey parameters are used such that consistent detection and location of IVS seed items are realized.

7.2.2 Data Requirements

TEMTADS dynamic data were collected with integrated navigation. Data were processed using project procedures determined during IVS data collection. Plan maps were plotted to confirm data cohesiveness. Line-to-line and along-line data points are reviewed for quality and data gaps, and the results documented. Data gaps are marked for fill-in data collection.

7.2.3 Success Criteria

The objectives are met if 90 percent across-track line separation is within 0.5 meter and 100 percent is within 0.7 meter, and 95 percent along-line data are within 15 cm and 100 percent are within 20 cm. This excludes obstructed areas.

7.2.4 Results

More than 99 percent of the dynamic data had an across track separation within 0.5 meters, and 100 percent were within 0.7 meters. Fill-in surveys were required in order to meet this metric.

More than 98.8 percent of data were within 15 cm when analyzing the along-track separation. However, the along-track objective was not met for all data collected, as the along-line data separation was within 20 cm for 99.9 percent of dynamic data.

7.3 OBJECTIVE: TOI DETECTION

The detection of all TOIs is a desired objective.

7.3.1 Metric

TEMTADS settings and survey parameters are used such that consistent detection and location of IVS and blind seed items are realized.

7.3.2 Data Requirements

The dynamic data are collected with integrated navigation. Data are processed using the project selection criteria. IVS and blind seeds are among all selected anomalies.

7.3.3 Success Criteria

The objectives are met if 100 percent of blind seeds are detected and 100 percent of IVS seeds are detected and within the specified detection metrics. This requirement is to confirm the detection system and to ensure the analyst is meeting these standards for known items.

7.3.4 Results

All items were detected during tests performed in dynamic mode at the IVS. Inversion of dynamic data was not a viable option with UXAnalyze at this time, so detection was based purely on monostatic amplitude responses over the IVS objects.

Of 28 blind seeds, one was not selected as a target during the detection survey. This was due to the seed being located at 0.5 meter depth, near the depth of detections for a medium ISO. Cued measurement made at this seed indicated a signal amplitude of only 0.92 mV/A while the target picking threshold was 1.4 mV/A.

7.4 OBJECTIVE: CUED DATA LOCATION

The detection location (dynamic) of all anomalies are near inverted locations (cued) is a desired objective.

7.4.1 Metric

TEMTADS setup on the reacquired location of the detection survey is coincident with the location based on the inversion of the cued data.

7.4.2 Data Requirements

The TEMTADS is set up on the reacquired location and cued data are collected. Data are checked in the field using TEMTADS software and the TEMTADS is moved to the revised location, if necessary, that results from the data modeled in the field. Cued data are then collected for classification.

7.4.3 Success Criteria

The objectives are met if 100 percent of the targets' modeled locations are within 40 cm of the center of the TEMTADS. Those that are greater than 40 cm will be recollected at the modeled source location. If the offset is still 40 cm, it will be assumed that this second modeled location is due to a second nearby target and the data are considered a success.

7.4.4 Results

With the exception of the category 0 targets, all of the targets' modeled locations were within 0.4 meter of the center of the TEMTADS. Twenty two category 0 target models were outside of the 0.4 meter metric. In order to increase the number of targets investigated, recollections were made in the field based on the NRL field inversion software. Recollections were not assigned based on UXAnalyze inversion results.

7.5 OBJECTIVE: CORRECTLY CLASSIFY TOIS

This objective requires the correct classification of all TOIs including seed items detected in the TEMTADS data.

7.5.1 Metric

TOI items found during the intrusive investigation are identified as such and were identified for digging.

7.5.2 Data Requirements

The cued TEMTADS data are collected at each anomaly detected in the dynamic data, processed, and, using signature library matching and training data, a prioritized dig list is created. The dig list categorizes each anomaly as "high-confidence TOI," "high-confidence non-TOI," and "can't analyze."

7.5.3 Success Criteria

The objective is met when 100 percent of TOIs are correctly classified and all the TOI and seed items are identified for intrusive investigation. Any "can't analyze" anomalies will also be included on the dig list.

7.5.4 Results

Of 28 blind seeds, 20 were correctly identified as TOIs, 4 as training digs, and 4 classified as "can't decide". The 4 seeds classified as "can't decide" were still above the stop dig threshold but were not classified as "high-confidence TOI" due to the UX-Analyze decision metric for their respective targets being below the decision metric threshold of .925 that was used as the cut-off point for high-confidence TOI.

Target 290013 corresponded to blind seed 312-QC16, a 4.2-inch mortar at 0.8 meters depth with a UX-Analyze decision metric of 0.857. Library matches to the modeled β1, β2, and β3 curves did not result in a good library match which did not display UXO-like characteristics. It is likely this seed was buried too deep for reliable classification.

Target 300014 corresponded to seed 312-QC09, a 75-mm at 0.4 meters depth. Analysis and classification resulted in a decision metric of 0.918, slightly below the high-confidence cut off point. The recovered polarizabilities did display UXO-like characteristics with the best β1, β2, and β3 library match to a 75-mm but smaller in size which affected the match results. The curves were also noisy during the later time gates which likely affected the match results. In retrospect this target should have been marked for training or the threshold for high-confidence TOI lowered.

Target 450024 (QA blind Seed V10) Small ISO at 0.2 meters depth has a decision metric of 0.8331. The recovered polarizabilities did display UXO-like characteristics with the best β1, β2, and β3 library match to a small ISO but smaller in size. The curves were also noisy and dropped during the later time gates which likely affected the match results. The target was noted as a possible training dig by the analyst but it wasn't categorized as such in the final dig list. In retrospect this target should have also been marked for training.

Two targets, Targets 390036 and 320017 (blind seed 312-QC16) corresponded to blind seed 312-QC16, a Medium ISO at 0.5 meters depth. Target 390036 resulted in a decision metric of 0.897. The recovered polarizabilities did not result in a good library match and did not display any UXO-like characteristics. The cued signal response for target 320017 was below the TEMTADS target selection threshold for RSA and the polarizability curves were poorly defined. As a result, UX-Analyze was unable to perform a library match. It is likely this seed was buried too deep for reliable classification with site conditions encountered at RSA.

An additional 26 digs resulted in TOI digs were investigated intrusively with 19 properly predicted as TOI. Nineteen of these were classified as TOI and the remaining 7 were classified as "can't decide". All non-seed related TOIs recovered during the intrusive investigation of TEMTADS targets were portions of M50-X Incendiary Bomblets.

Given the single pass of library validation and digging performed, the polarizability library entries did not change based on incoming dig results, and M50-X bomblets or their subsections were not included in the library. Library entries cannot be selected that would effectively provide matches to every M50-X piece on site, as their variability in shaft length is essentially unlimited. However, the sections of the M50-X bomblet found on site, as shown in **Figure 7-1**, matched with some success to other existing TOIs in the polarizability library. Section A matched to a 40-mm grenade, and sections B and AB matched to Aluminum rifle grenades. The modeled polarizabilities of one smaller piece of the explosive charge identified as material potentially presenting an explosive hazard (MPPEH), matched to existing fuze components in the library.

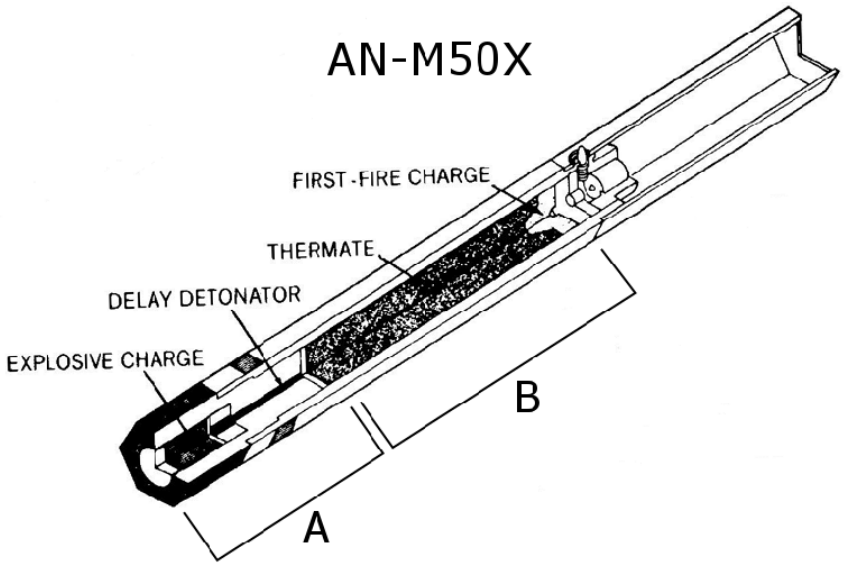

Figure 7-1 Typical Sections of M50-X bomblets Found on Site

7.6 OBJECTIVE: CORRECTLY CLASSIFY NON-TOIS

The detected anomalies that are not TOIs are classified as non-TOIs. This objective shows the effectiveness of the classification system at reducing the number of excavations.

7.6.1 Metric

Only a percentage of non-TOI-classified items are dug, and most non-TOIs items are identified as such and are not identified for digging.

7.6.2 Data Requirements

The cued TEMTADS data are collected at each anomaly detected in the dynamic data, processed, and, using signature library matching and training data, a prioritized dig list is created. The dig list categorizes each anomaly as “high-confidence TOI,” “high-confidence non-TOI,” and “can’t analyze.”

7.6.3 Success Criteria

The objectives are met if 70 percent of non-TOIs were correctly classified.

7.6.4 Results

This objective was met. Of the 164 non-TOIs items investigated intrusively, 70.12 percent of non-TOIs were correctly identified as non-TOIs. This number would improve significantly after the removal of fuze components from the polarization library, which accounted for 37 percent of the non-TOI items that were identified as TOIs or potential TOIs. There was only one instance were a match to a fuze component corresponded to a dig that was MPPEH and therefore considered a TOI, but not of typical UXO-like shape.

7.7 OBJECTIVE: MINIMIZE "CAN'T ANALYZE" ANOMALIES

When data cannot be analyzed, the anomaly cannot be classified. These anomalies must be dug, thus increasing the number of digs, potentially digging non-TOI, and reducing the effectiveness of the advanced classification program.

7.7.1 Metric

Minimize the number of "can't analyze" anomalies.

7.7.2 Data Requirements

The cued TEMTADS data are collected following best practices at each anomaly to minimize the number of anomalies that can't be analyzed, and to maximize the number of anomalies that can be reliably classified.

7.7.3 Success Criteria

The objectives are met if 95 percent of all the anomalies have clean, reliable data, therefore leaving 5 percent of cued data classified as "can't analyze." Additionally, CB&I expects that the analyst will classify 5 percent of the anomalies as "can't decide."

7.7.4 Results

This objective was met with 3.06 percent of cued data measurements having modeled polarizabilities that resulted in can't analyze categorization.

7.8 OBJECTIVE: CORRECTLY PLACE THE STOP-DIG THRESHOLD

The "stop dig" threshold is the dividing line between the digs and the no-digs. The objective is that all TOIs, seed items, "can't analyze" anomalies, and validation anomalies are above the stop-dig threshold and the non-TOI are below it. This objective shows the effectiveness of the classification system at reducing the number of excavations.

7.8.1 Metric

All TOIs, seed items, "can't analyze," and validation-check anomalies are dug, and most non-TOI items are identified as such and are not identified for digging.

7.8.2 Data Requirements

The dig list, including classification results and excavation results, is analyzed and a ROC curve is prepared.

7.8.3 Success Criteria

The objectives are met if the ROC curve is steep and 70 percent of non-TOIs are below the stop dig threshold and 100 percent of TOI are above the stop-dig threshold.

7.8.4 Results

This objective was met with one caveat. A TOI-like section of an M50-X was below the stop dig threshold. However, this target was shared with another measurement that placed it above the stop-dig point. Additionally this target had polarizabilities that were not modeled conclusively by UX-analyze resulting in no library match for the best multi-item polarizabilities. Even though a decision metric was assigned that placed it in category 3, it should have been assigned to category 0. The difficulty with the M50 is the hex part of the M50 can be any size or shape when not intact and still be considered UXO/MEC. Note that a ROC curve was not created for this demonstration due to the limited number of intrusive investigations relative to the total target list.

7.9 OBJECTIVE: CORRECT ANOMALY LOCATION

The modeled location from the cued data accurately depicts the location (laterally and vertically) of the anomaly source.

7.9.1 Metric

The metric is the offset between the inverted anomaly location and the excavated location.

7.9.2 Data Requirements

The dig list x, y coordinates and depths (inversion results) and the dig team's offset between the dig list and recovered locations are compared.

7.9.3 Success Criteria

The objectives are met if 90 percent of the two location total offset is within 25 cm and the depths are within 10 cm.

7.9.4 Results

The horizontal offset objective was narrowly not met, as 89.524 percent of measured horizontal dig locations were within 25 cm of the predicted location. The objective regarding depth offsets was not met as 79.82 percent of measured dig depths were within 10 cm predicted depth, and of note is that more than 96 percent of the predicted depths were within 25 cm of ground truth.

7.10 ADDITIONAL OBJECTIVES

An overlying goal of this project is the detection and classification of large munitions, such as 4.2-inch mortars at a depth of approximately 90 cm. While no preexisting TOI of this size were discovered during the intrusive investigations, six seeds including 4.2-inch mortars and Large ISOs were detected and cued during the demonstration. The nature of their similarities in size and polarizabilities are shown in **Figure 7-2** with the library entries for their polarizabilities.

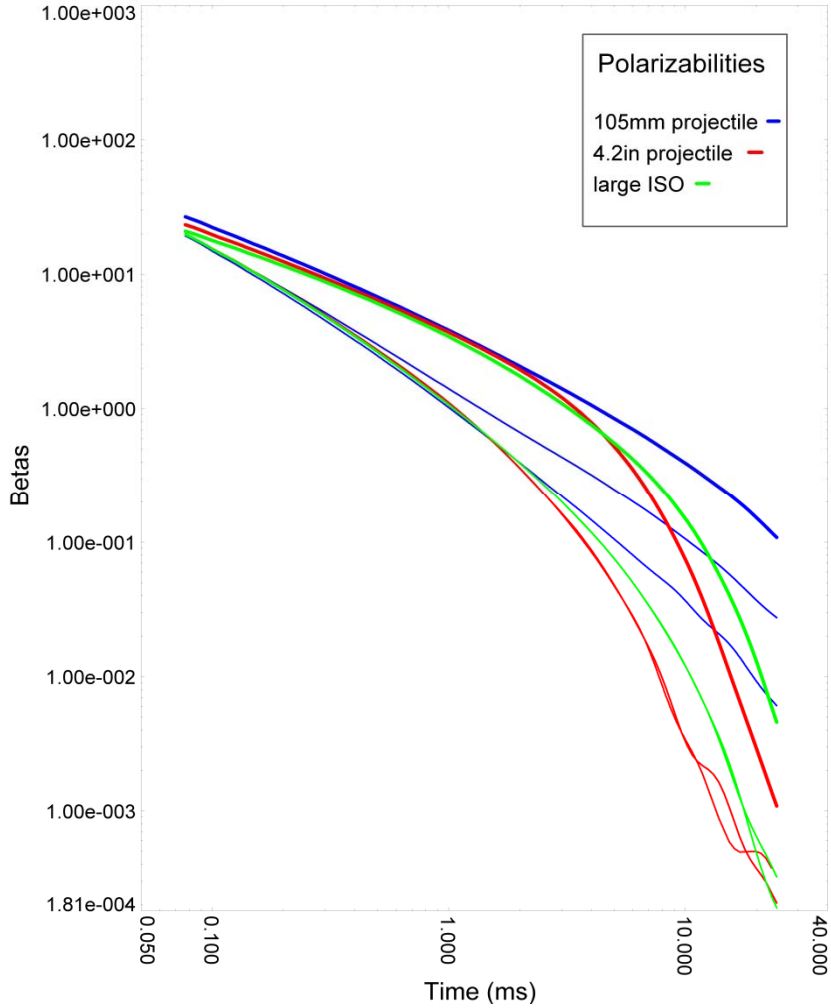

Figure 7-2 Reference Polarizabilities for 4.2-inch Mortars and Surrogates

Of the six seeds of comparable size with a 4.2-inch mortar, emplacement depths ranged from 45 cm to 80 cm below ground surface. The two deepest of these had decision metrics below 0.925 threshold used for high-confidence TOIs. A 0.923 decision statistic was obtained for a 105-mm at 70 cm and a 0.857 decision statistic was obtained for a 4.2-inch mortar at 80 cm. A large ISO, whose depth of emplacement was also 60 cm had a decision metric of 0.972.

8.0 COST ASSESSMENT

This section presents cost and production data for the TEMTADS demonstration at RSA.

8.1 PRODUCTION DATA

The TEMTADS Demonstration at RSA included:

- Dynamic data collection: 8.21 acres
- Cued data collection: 1,178 targets
- Subsurface investigations: 221 targets

8.1.1 Dynamic Surveys

CB&I collected dynamic TEMTADS data over an area of 8.21 acres.

After site preparation, the dynamic mapping was completed in 38 survey days for an average production of 0.22 acres/day.

The mapping required a crew of two geophysicists. An additional geophysicist was used at times for purposes of training.

8.1.2 Cued Surveys

CB&I cued a total of 1,178 targets.

The cued data collection was completed in 17 survey days. On two days, production was severely limited by rain. Based on 15 effective days, the average production was about 80 targets/day.

The cued survey required a crew of two geophysicists. An additional geophysicist was used at times for purposes of training.

8.1.3 Subsurface Investigations

RSA-073 is part of a larger site on Redstone Arsenal, RSA-312, undergoing site characterization as part of on-going environmental corrective measures. The TEMTADS anomalies selected for excavation were intrusively investigated during the same time as a much larger set of geophysical anomalies previously mapped by a separate and independent EM-61 geophysical team. The TEMTADS anomaly data were beneficially used by the project team, but subsurface investigation costs for the TEMTADS anomalies were not separately captured.

8.2 COST BREAKDOWN

Table 8-1 provides an overview of the costs expended for the demonstration at RSA. This table shows costs as invoiced with travel and equipment broken out to separate cost codes. Costs are shown through April 2017 plus an estimate of costs to complete the report. Costs do not include fees.

Table 8-2 shows costs for each major project task, with subcontracts, travel, and equipment distributed by task. Again, costs are estimated through completion of the report.

These costs do not include the following items provided by ESTCP or the RSA Installation:

- TEMTADS rental
- Subsurface investigations (provided by Installation contractor)
- Disposal of MEC and MD (provided by Installation contractor)
- Facilities support (storage, office space, telecommunications – provided by Installation)

Subcontracted costs included Acorn Software who provided technical support for dig list development, and Mid-South Testing who provided surveying of seed and anomaly locations.

Unit costs for activities such as dynamic or cued surveys are not provided because they are distorted on the one hand by costs absorbed by the Installation and on the other hand by significant investments in training multiple CB&I geophysicists.

Table 8-1 Costs as Invoiced, Advanced Classification Demonstration, RSA

Budget element	As Invoiced	% of Total
Project set up and work plan	19,820	4%
Site and Equipment Prep	7,966	2%
Subcontracts and equipment	81,757	16%
DGM field (incl escort)	149,605	30%
DGM home office	150,460	30%
Subsurface investigations (incl geo)	308	0%
Travel (hotel and perdiem)	44,893	9%
Report	19,304	4%
Project management	32,551	6%
	506,664	

Table 8-2 Cost Breakdown by Task, Advanced Classification Demonstration, RSA

Budget element	Cost by Task	% of Total
Project set up and work plan	19,820	4%
Site and Equipment Prep	7,966	
Dynamic surveys	160,816	31%
Cued surveys	53,914	11%
DGM home office	211,985	42%
Subsurface investigations (incl geo)	308	0%
Report	19,304	5%
Project management	32,551	6%
	506,664	

9.0 IMPLEMENTATION ISSUES

Data collection and processing phases of work were completed with minimal obstacles once initial problems with the TEMTADS unit and the use of RTS positioning had been worked out. The majority of implementation issues were associated with software and are discussed below.

At the beginning of 2016, a portion of the previously available TEMTADS units from NRL were reaching the end of their operating lifetime. Variants of the TEMTADS were not yet commercially available, making time with the NRL TEMTADS unit limited due to obligations of the remaining operable units at other projects. The initial TEMTADS unit from NRL was determined to be malfunctioning, and the electronics unit swapped with another unit recently demobilized from another contractor. During field work, rain was common, and instructions from NRL staff were to avoid any rain. This created significant delays in initial testing and data collection. Combined with the limitations of RTS positioning in the rain, this resulted in significant field work delays due to weather.

Importing TEMTADS data with RTS based positioning into Oasis Montaj proved a challenge at the beginning of testing. A custom GX was written to provide correct positioning information for the .gps files recorded by the TEMTADS unit in cued mode, requiring extra steps during preprocessing. However, by the time data processing was undertaken, resource files, provided by Acorn, were applied to Oasis Montaj 8.5.2 allowing for the direct import of cued data with RTS positioning. Additionally, it was determined that the Trimble S7 provided a more consistent data stream than a Leica TPS system initially selected for positioning.

The initial intent of the project was to generate source models from dynamic data as well as cued data. At the time of the demonstration, dynamic processing capabilities of UX-Analyze were still not fully mature. Dynamic TEMTADS data could be loaded into a beta version of Oasis Montaj 9.0 or with customized resource files from Acorn, but not through version 8.5.5, current at that time. More importantly, the ability to perform inversions with dynamic data was not present.

Because of the variability of signature for an M50, it is not feasible to attempt to add this item to the match library. Furthermore, if smaller lengths are added to the match library the likelihood of matches of small debris increases and the goal of reducing the numbers of digs will not be realized. At this point the project team decides if the M50 is considered a TOI and whether an alternative strategy specific to the M50 is necessary.

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10.0 REFERENCES

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Parsons, *Draft Demonstration Plan MetalMapper at Former Camp Beale,* ESTCP Project No. MR-201104.

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U.S. Naval Research Laboratory, Chemistry Division, MTADS Program, 2014, *User's Guide.*

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APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name Address	Phone Fax Email	Role in Project
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Andrew Gritz	CB&I Federal Services 4005 Port Chicago Hwy Concord, CA 94520	925-288-2180 Andrew.Gritz@CBIFederalServices.com	Analyst
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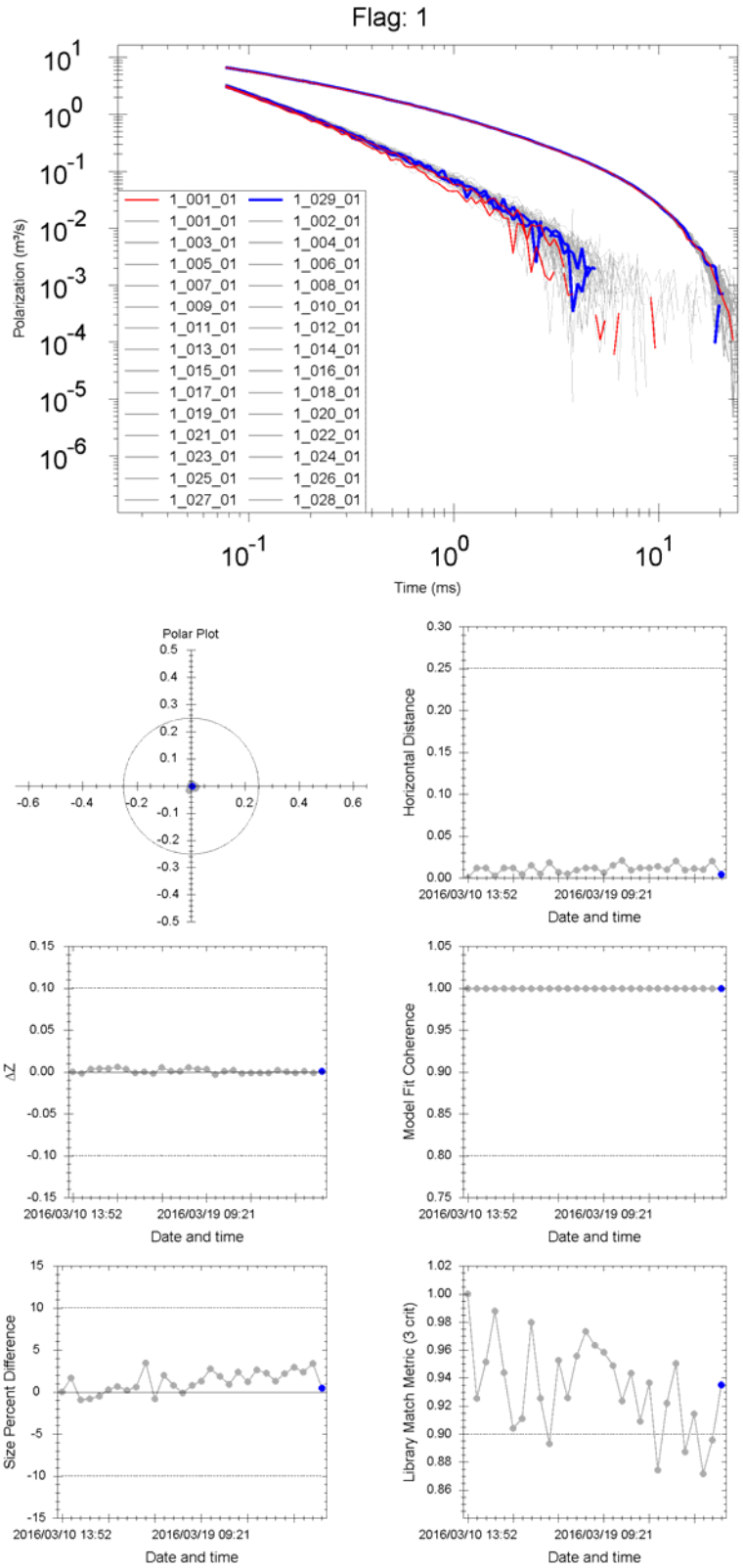
APPENDIX B IVS RESULTS

Cued IVS Results

	Known Position Check (≤ 0.15 m)		Derived Match (≥ 0.9)								Fit location (< 0.25 m)							
	AM Δ-XY	PM Δ-XY	Item #1 (AM)	Item #2 (AM)	Item #3 (AM)	Item #4 (AM)	Item #1 (PM)	Item #2 (PM)	Item #3 (PM)	Item #4 (PM)	Item #1 (AM)	Item #2 (AM)	Item #3 (AM)	Item #4 (AM)	Item #1 (PM)	Item #2 (PM)	Item #3 (PM)	Item #4 (PM)
3/10/2016	0.028	NA	1	1	1	1	NA	NA	NA	NA	0.054	0.078	0.305	0.086	NA	NA	NA	NA
3/11/2016	0.023	0.023	0.9256	0.9959	0.9962	0.9905	0.9513	0.997	0.9832	0.9913	0.064	0.086	0.318	0.078	0.067	0.085	0.323	0.078
3/12/2016	0.024	0.019	0.9879	0.9942	0.9786	0.9762	0.9437	0.9971	0.9712	0.9918	0.058	0.078	0.320	0.086	0.064	0.078	0.320	0.086
3/13/2016	0.023	0.020	0.9041	0.9939	0.9775	0.995	0.9111	0.9949	0.9844	0.9979	0.064	0.085	0.310	0.078	0.045	0.081	0.307	0.078
3/15/2016	0.024	0.031	0.9797	0.9968	0.9635	0.9968	0.9254	0.9968	0.9633	0.9605	0.064	0.086	0.332	0.078	0.058	0.078	0.332	0.086
3/16/2016	0.033	0.017	0.8930	0.9871	0.9875	0.9956	0.9525	0.9951	0.9869	0.986	0.063	0.078	0.300	0.092	0.058	0.078	0.323	0.086
3/17/2016	0.019	0.028	0.9258	0.9967	0.9574	0.9951	0.9557	0.9968	0.9814	0.9944	0.058	0.078	0.314	0.086	0.058	0.078	0.323	0.081
3/18/2016	0.020	0.018	0.9731	0.9968	0.9779	0.9807	0.9634	0.9925	0.9936	0.9957	0.063	0.078	0.331	0.078	0.064	0.086	0.301	0.081
3/19/2016	0.018	0.017	0.9585	0.9964	0.9836	0.9946	0.9488	0.9953	0.993	0.9937	0.054	0.072	0.314	0.078	0.063	0.078	0.331	0.078
3/20/2016	0.031	0.026	0.9236	0.9973	0.9403	0.9966	0.9436	0.9929	0.9558	0.9932	0.071	0.086	0.332	0.072	0.050	0.081	0.335	0.072
3/21/2016	0.022	0.025	0.9092	0.9938	0.9669	0.9895	0.9365	0.9908	0.986	0.9874	0.057	0.078	0.326	0.072	0.057	0.081	0.320	0.072
3/22/2016	0.025	0.021	0.8742	0.9877	0.9684	0.9823	0.9219	0.9902	0.9873	0.9818	0.064	0.086	0.327	0.086	0.058	0.086	0.314	0.078
3/23/2016	0.018	0.017	0.9503	0.9957	0.9602	0.9919	0.8873	0.9944	0.9816	0.9788	0.064	0.081	0.342	0.081	0.058	0.078	0.320	0.072
3/25/2016	0.021	0.025	0.9143	0.9922	0.988	0.9812	0.8715	0.9945	0.9762	0.988	0.057	0.086	0.301	0.078	0.058	0.078	0.309	0.072
3/26/2016	0.024	0.026	0.8956	0.9915	0.9803	0.9861	0.9352	0.9941	0.984	0.989	0.072	0.078	0.327	0.078	0.058	0.078	0.314	0.078

*It seems likely that ground truth measurement was recorded improperly for IVS item #3. It is possible that the surveyor record the nose of the 4.2” Mortar instead of the center.

Ongoing Cued IVS Tests By Item (Flag)



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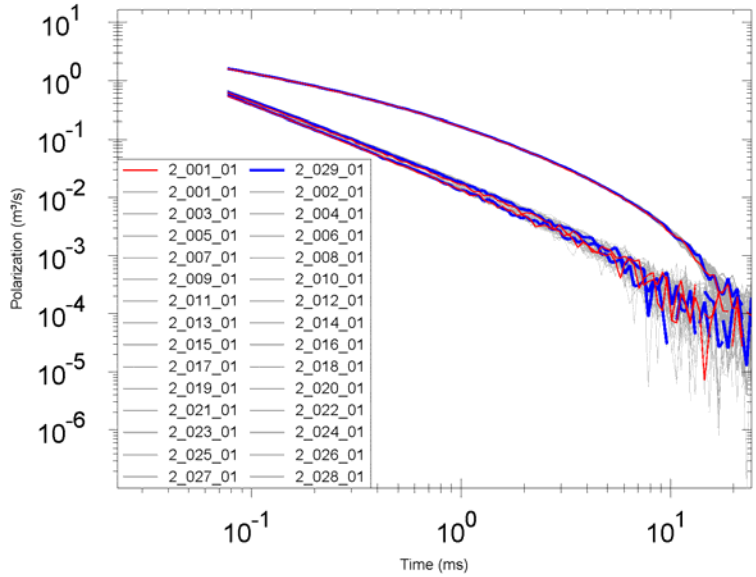
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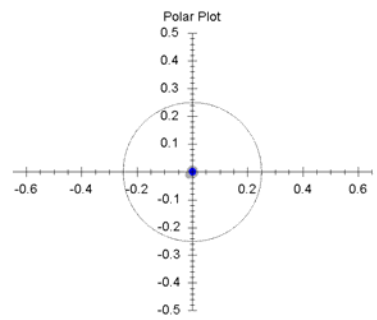
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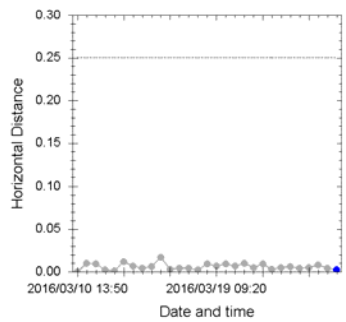
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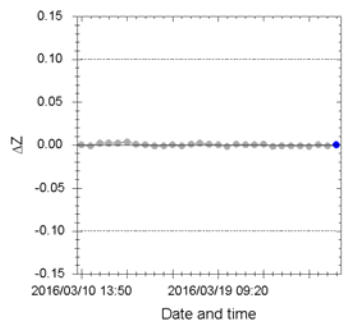
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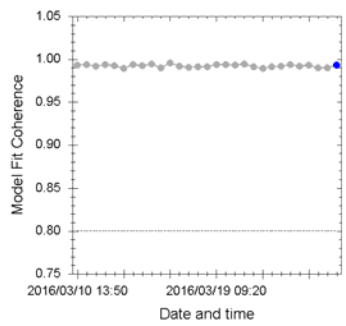
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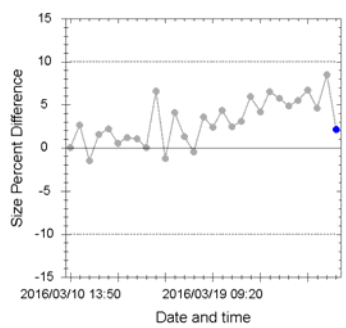
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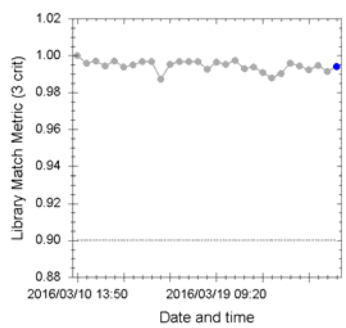
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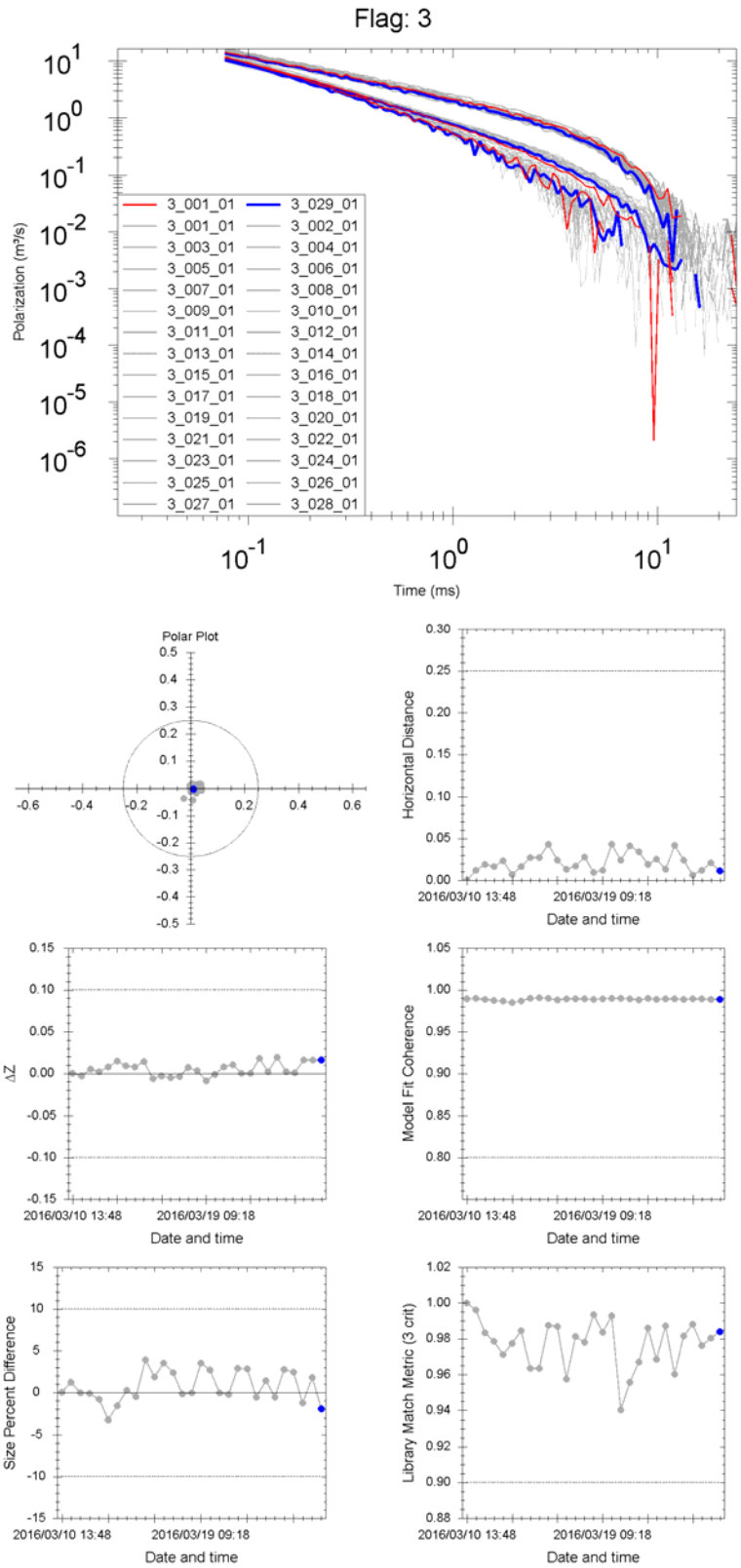
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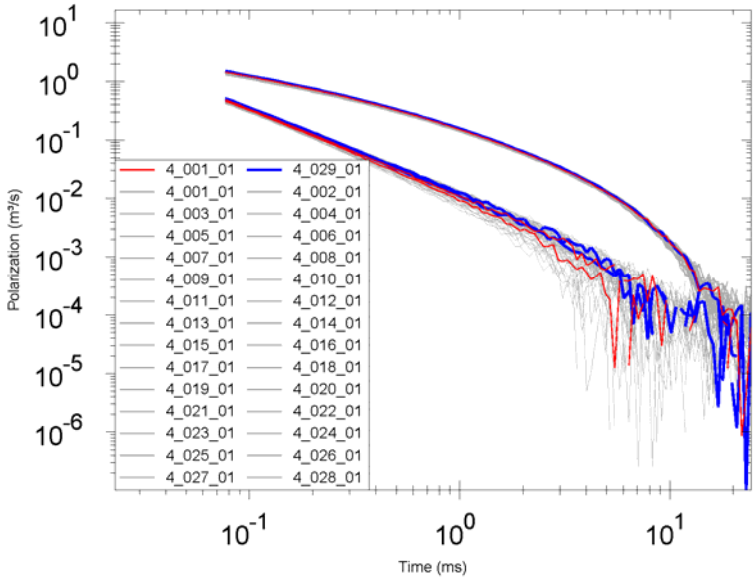
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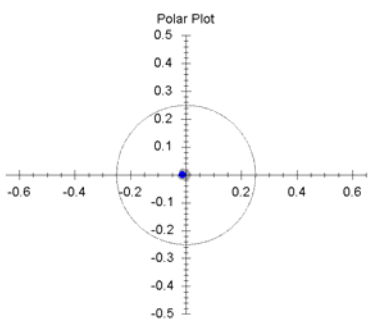
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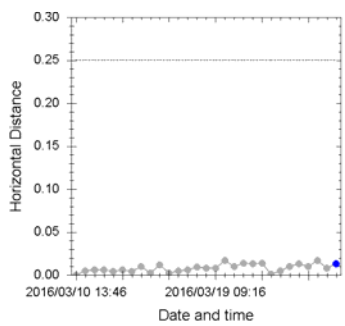
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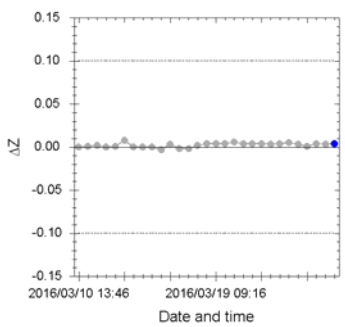
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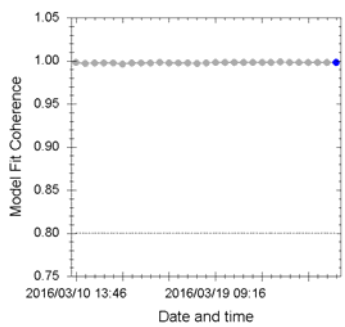
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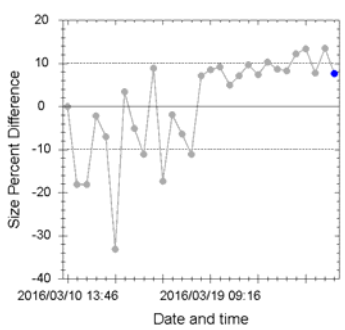
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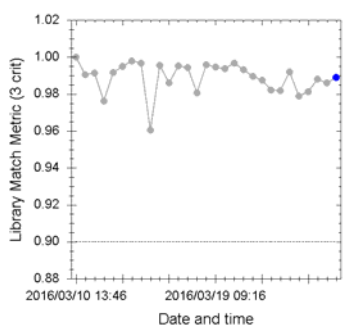
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Dynamic IVS Amplitude Repeatability Results (As a percent of average of first four runs)

	Item 1				Item 2				Item 3				Item 4			
	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4
11/17/2015	100.70%	103.77%	102.85%	99.81%	99.53%	99.41%	101.08%	98.57%	93.23%	103.45%	99.13%	101.35%	96.43%	101.25%	104.06%	99.55%
11/17/2015	97.02%	99.57%	103.84%	99.32%	102.06%	101.74%	100.29%	99.62%	104.40%	98.47%	100.08%	101.29%	103.83%	97.09%	100.84%	101.37%
11/17/2015	98.83%	99.78%	105.00%	97.70%	100.84%	100.47%	97.94%	101.70%	108.20%	95.40%	97.82%	101.95%	99.44%	101.61%	97.45%	101.32%
11/17/2015	104.24%	96.82%	93.51%	102.05%	98.05%	99.94%	99.41%	97.37%	96.96%	102.07%	98.59%	100.32%	102.73%	97.45%	97.32%	100.20%
11/17/2015	99.21%	100.06%	94.80%	101.12%	99.53%	98.45%	101.27%	102.74%	97.21%	100.60%	104.38%	95.09%	97.57%	102.60%	100.33%	97.55%
11/17/2015	103.21%	100.67%	101.25%	99.13%	99.27%	99.19%	99.22%	98.57%	98.90%	101.80%	102.03%	98.36%	97.57%	99.91%	100.76%	97.93%
11/20/2015	102.82%	98.33%	99.96%	98.44%	95.52%	95.05%	95.78%	93.12%	90.63%	108.16%	99.54%	97.56%	102.59%	97.27%	94.83%	100.44%
11/20/2015	97.80%	100.95%	99.10%	92.66%	95.61%	96.64%	95.78%	93.52%	98.90%	103.76%	104.61%	97.82%	103.83%	98.43%	94.87%	104.99%
12/3/2015	103.15%	103.84%	99.29%	97.64%	93.52%	93.56%	92.25%	93.44%	99.13%	99.45%	97.73%	99.13%	102.64%	95.93%	92.56%	101.60%
12/3/2015	101.86%	101.64%	97.87%	95.08%	94.65%	92.71%	93.33%	95.13%	106.06%	91.45%	96.78%	99.47%	97.53%	98.93%	98.18%	100.86%
12/4/2015	101.86%	100.67%	93.38%	98.63%	95.18%	93.35%	91.37%	93.60%	93.92%	103.36%	98.04%	98.36%	101.16%	96.73%	95.43%	100.02%
12/4/2015	102.95%	102.39%	102.11%	96.08%	94.74%	93.78%	93.73%	93.93%	102.85%	95.54%	90.53%	105.70%	104.40%	94.18%	94.40%	101.46%
12/7/2015	101.79%	101.57%	99.59%	97.70%	95.09%	93.14%	92.94%	93.36%	98.19%	105.23%	99.40%	94.86%	101.92%	96.33%	99.30%	100.20%
12/7/2015	105.98%	98.47%	98.49%	100.37%	95.79%	94.20%	93.24%	97.29%	96.70%	103.89%	101.17%	98.93%	101.16%	97.81%	98.57%	100.62%
12/9/2015	105.13%	96.69%	98.15%	100.00%	96.51%	94.83%	94.32%	96.07%	94.68%	107.79%	102.66%	96.22%	95.64%	100.66%	101.29%	100.85%
12/9/2015	99.62%	105.79%	95.54%	100.73%	95.44%	94.00%	94.03%	96.42%	97.48%	104.42%	98.25%	100.20%	103.98%	96.83%	91.10%	104.32%
12/10/2015	103.35%	101.05%	94.90%	101.39%	95.23%	93.76%	94.44%	95.38%	103.53%	99.63%	101.59%	99.81%	100.52%	99.87%	94.75%	100.32%
12/10/2015	105.72%	105.49%	101.44%	99.38%	97.00%	95.48%	95.10%	96.33%	100.30%	105.81%	101.39%	98.82%	101.87%	97.40%	99.30%	103.88%
12/11/2015	108.92%	102.88%	99.05%	99.54%	96.64%	97.09%	97.80%	97.43%	99.80%	96.88%	94.47%	103.18%	101.85%	98.50%	95.46%	101.75%
12/11/2015	109.35%	106.13%	100.16%	103.03%	100.05%	99.05%	97.15%	97.09%	98.95%	106.60%	101.97%	100.91%	105.78%	96.43%	96.07%	104.76%
12/14/2015	105.29%	102.17%	95.55%	101.91%	97.54%	97.54%	95.84%	97.23%	99.82%	101.92%	95.65%	103.10%	104.06%	97.75%	95.18%	106.54%
12/14/2015	106.16%	102.62%	98.33%	100.66%	99.39%	97.23%	99.74%	99.72%	98.35%	101.84%	93.97%	103.33%	105.18%	96.40%	97.70%	106.28%
12/15/2015	105.08%	101.16%	98.36%	96.45%	98.40%	95.58%	94.12%	96.97%	105.31%	96.47%	96.01%	100.18%	102.64%	98.88%	94.44%	102.30%
12/15/2015	101.21%	105.28%	97.75%	98.94%	98.40%	96.64%	94.12%	96.17%	102.74%	104.03%	99.18%	101.04%	103.11%	97.54%	100.88%	105.55%
12/16/2015	102.50%	106.66%	102.05%	96.45%	95.79%	95.58%	97.06%	93.77%	97.87%	102.25%	94.19%	102.46%	104.54%	95.75%	98.31%	105.55%
12/16/2015	101.21%	103.22%	97.14%	101.43%	99.27%	97.71%	98.04%	96.97%	105.88%	97.80%	92.84%	104.17%	105.50%	96.20%	100.88%	105.55%
12/17/2015	101.21%	107.28%	101.75%	100.31%	97.18%	95.58%	95.00%	95.21%	97.16%	106.70%	98.77%	98.82%	102.16%	98.30%	100.24%	104.44%
12/17/2015	98.57%	105.63%	100.15%	102.12%	97.00%	96.75%	94.31%	96.89%	100.36%	105.49%	99.18%	99.10%	105.79%	95.79%	98.09%	105.37%
12/18/2015	103.86%	99.78%	95.35%	96.08%	95.61%	95.05%	94.71%	96.01%	94.27%	104.43%	96.01%	102.15%	104.35%	94.94%	91.74%	103.69%
12/18/2015	103.92%	98.33%	92.28%	98.88%	95.96%	93.67%	93.14%	96.09%	101.22%	105.45%	100.22%	97.36%	105.17%	95.70%	95.52%	105.55%
1/29/2016	98.85%	98.77%	96.31%	99.83%	98.71%	99.11%	98.79%	100.44%	104.50%	107.05%	99.13%	100.95%	98.33%	98.88%	97.20%	101.38%
2/3/2016	99.90%	100.20%	102.97%	102.55%	101.25%	101.11%	100.88%	101.12%	94.85%	108.53%	102.00%	98.77%	102.21%	99.07%	99.59%	100.70%
2/3/2016	101.64%	106.22%	105.25%	99.17%	100.35%	101.55%	100.88%	100.52%	102.43%	101.72%	102.13%	100.98%	100.01%	101.72%	100.09%	100.24%
2/4/2016	96.43%	99.11%	94.92%	96.62%	99.98%	100.00%	99.42%	98.75%	99.25%	99.27%	100.13%	97.83%	101.46%	99.84%	100.32%	99.05%
2/4/2016	103.19%	95.70%	100.56%	101.83%	99.71%	98.23%	100.04%	99.17%	98.97%	92.26%	96.61%	101.47%	98.00%	100.49%	102.80%	98.64%
2/5/2016	100.09%	96.99%	97.51%	101.10%	98.07%	97.67%	99.42%	99.59%	98.52%	102.78%	99.61%	98.97%	97.58%	101.95%	99.05%	98.00%
2/5/2016	96.99%	103.14%	101.26%	97.89%	99.16%	99.11%	99.42%	100.02%	98.43%	102.70%	95.22%	101.21%	100.34%	99.52%	103.47%	99.14%
2/8/2016	100.83%	98.29%	104.30%	100.31%	99.16%	97.01%	99.94%	97.65%	102.89%	98.13%	97.00%	99.44%	97.58%	98.56%	102.30%	97.68%
2/8/2016	96.18%	100.07%	98.34%	96.50%	98.07%	98.45%	99.21%	100.35%	101.74%	96.38%	99.70%	99.78%	100.20%	99.07%	101.35%	101.56%
2/9/2016	102.57%	97.27%	99.16%	100.50%	96.99%	97.12%	97.54%	97.99%	101.25%	100.21%	93.56%	103.48%	95.57%	102.59%	102.03%	100.05%
2/9/2016	102.07%	97.06%	98.21%	101.95%	93.44%	94.46%	97.85%	97.82%	97.70%	104.37%	97.43%	101.59%	94.59%	102.82%	99.10%	95.57%
2/10/2016	94.76%	96.72%	97.77%	100.25%	94.08%	94.57%	95.87%	94.88%	91.88%	105.23%	91.61%	98.91%	96.32%	98.24%	103.29%	96.95%
2/10/2016	99.03%	100.68%	103.03%	100.74%	96.99%	98.67%	96.71%	96.30%	97.79%	102.50%	92.30%	104.39%	97.20%	99.48%	101.04%	98.91%
2/11/2016	99.90%	99.32%	98.66%	98.92%	95.08%	94.35%	97.96%	97.14%	102.22%	98.25%	96.96%	98.91%	98.37%	98.65%	100.86%	100.10%
2/11/2016	102.07%	99.66%	100.81%	98.92%	99.71%	99.22%	99.52%	99.76%	105.62%	95.81%	95.61%	101.91%	100.15%	99.75%	100.81%	99.78%
2/12/2016	100.71%	98.43%	100.18%	96.81%	97.08%	97.23%	98.27%	99.43%	103.77%	91.20%	95.87%	100.95%	100.62%	99.57%	94.50%	99.19%

	Item 1				Item 2				Item 3				Item 4			
	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4
2/12/2016	99.41%	101.09%	104.05%	101.89%	98.62%	99.11%	101.40%	101.12%	85.57%	101.48%	96.39%	103.74%	101.04%	97.05%	97.38%	103.39%
2/17/2016	91.16%	98.63%	99.42%	89.91%	96.08%	96.35%	99.42%	100.86%	86.60%	94.83%	92.56%	104.50%	98.33%	100.62%	99.10%	99.73%
2/17/2016	93.89%	100.48%	96.44%	96.74%	97.17%	96.79%	100.88%	97.48%	99.85%	97.48%	97.96%	100.57%	101.60%	94.62%	100.00%	98.96%
2/18/2016	97.86%	97.81%	95.61%	95.29%	97.17%	97.23%	97.75%	97.14%	101.10%	96.70%	94.82%	102.46%	100.85%	96.68%	98.92%	102.34%
2/18/2016	95.31%	103.69%	103.09%	93.60%	98.53%	100.33%	102.54%	100.27%	97.76%	103.19%	91.56%	105.23%	101.65%	96.18%	97.79%	100.70%
2/19/2016	95.19%	103.07%	108.55%	95.17%	100.44%	98.34%	100.77%	101.54%	111.14%	86.43%	95.04%	104.59%	96.13%	99.98%	101.08%	98.64%
2/19/2016	95.25%	102.80%	98.15%	93.48%	100.16%	105.09%	105.04%	103.14%	87.02%	98.34%	94.65%	104.44%	103.94%	95.31%	96.93%	102.57%
2/20/2016	97.05%	104.23%	98.91%	94.75%	102.43%	100.66%	101.29%	100.44%	105.07%	98.70%	98.17%	102.43%	99.82%	100.03%	97.16%	100.19%
2/20/2016	96.55%	104.64%	110.39%	93.11%	100.80%	100.00%	100.77%	100.61%	107.04%	96.58%	94.56%	102.26%	97.44%	103.33%	102.53%	101.06%
2/22/2016	94.51%	102.66%	97.45%	94.08%	101.25%	99.89%	100.25%	99.51%	98.67%	98.58%	92.13%	104.50%	100.15%	98.10%	101.13%	101.24%
2/22/2016	94.63%	100.89%	110.45%	93.96%	100.44%	101.55%	103.06%	100.86%	114.69%	83.20%	92.17%	108.43%	101.69%	97.65%	94.27%	103.16%
2/23/2016	95.50%	103.35%	105.82%	92.27%	99.35%	98.45%	100.15%	99.09%	101.64%	102.05%	98.22%	101.47%	102.39%	98.15%	96.48%	101.88%
2/23/2016	98.54%	103.76%	98.21%	94.81%	100.16%	101.33%	102.75%	101.28%	104.98%	100.13%	97.04%	100.45%	100.85%	99.84%	100.27%	102.39%
2/25/2016	95.44%	97.54%	104.11%	95.66%	97.80%	97.34%	98.90%	97.74%	102.28%	94.75%	97.26%	101.59%	95.43%	92.52%	95.22%	98.91%
2/25/2016	96.80%	99.66%	94.85%	96.56%	98.26%	99.67%	103.27%	100.61%	101.52%	102.13%	94.69%	103.34%	97.02%	94.39%	98.56%	101.88%
2/26/2016	97.73%	95.29%	98.47%	91.12%	99.35%	96.79%	97.44%	98.41%	108.86%	90.30%	90.26%	104.24%	98.79%	93.11%	103.25%	98.87%
2/26/2016	98.54%	94.81%	94.98%	94.32%	98.17%	98.89%	101.40%	98.67%	98.19%	105.31%	98.04%	96.47%	98.23%	94.94%	95.99%	101.34%
2/27/2016	96.99%	105.94%	102.46%	90.63%	97.17%	97.56%	97.02%	97.82%	100.92%	98.46%	95.95%	99.76%	98.19%	97.55%	96.03%	100.70%
2/27/2016	98.17%	103.14%	98.40%	95.47%	100.62%	101.55%	104.11%	100.02%	101.25%	100.13%	94.91%	100.48%	94.49%	102.87%	104.74%	101.20%
2/28/2016	96.49%	103.01%	107.47%	91.48%	98.35%	98.45%	99.21%	97.74%	103.65%	96.26%	95.30%	99.96%	99.03%	97.74%	100.63%	103.26%
2/28/2016	95.44%	106.69%	99.29%	93.96%	102.89%	102.33%	104.31%	102.97%	97.40%	101.52%	96.35%	101.42%	95.47%	105.25%	99.05%	100.74%
2/29/2016	99.90%	99.80%	99.86%	95.84%	101.62%	101.88%	102.65%	101.71%	104.10%	92.30%	95.04%	101.21%	98.14%	100.21%	102.93%	95.16%
2/29/2016	99.10%	103.28%	110.20%	95.17%	101.16%	101.77%	104.21%	101.28%	101.37%	102.01%	96.00%	102.35%	101.74%	99.39%	99.82%	103.03%
3/2/2016	97.61%	102.73%	102.33%	93.96%	98.53%	98.89%	97.85%	100.02%	98.37%	101.31%	95.08%	99.52%	97.86%	101.86%	99.50%	97.40%
3/2/2016	96.12%	102.73%	96.69%	91.42%	100.07%	100.33%	101.40%	98.67%	106.35%	95.93%	94.35%	103.57%	102.49%	96.00%	96.17%	105.04%
3/4/2016	92.28%	102.80%	103.85%	95.78%	97.62%	99.34%	100.25%	101.12%	101.31%	98.46%	96.39%	97.08%	94.16%	103.87%	97.93%	100.97%
3/4/2016	94.57%	101.71%	105.38%	93.11%	98.71%	99.22%	102.33%	100.95%	99.79%	99.64%	92.26%	101.07%	98.19%	101.95%	104.60%	98.73%
3/5/2016	93.27%	100.48%	99.29%	92.15%	96.80%	99.22%	99.94%	100.19%	99.22%	92.75%	92.43%	103.83%	93.42%	99.75%	97.88%	97.22%
3/5/2016	94.82%	105.26%	102.08%	91.18%	100.62%	101.66%	105.98%	102.72%	101.58%	95.73%	93.34%	103.92%	99.21%	98.84%	102.39%	100.42%
3/6/2016	100.02%	94.95%	102.90%	96.93%	98.26%	101.55%	99.31%	98.50%	108.56%	90.06%	91.87%	103.45%	102.67%	95.54%	98.24%	99.32%
3/6/2016	101.88%	94.95%	96.94%	94.87%	102.07%	101.99%	103.90%	100.19%	107.59%	96.38%	94.52%	102.14%	101.37%	98.93%	99.10%	102.52%
3/7/2016	96.74%	96.65%	107.41%	96.32%	99.80%	99.89%	104.21%	101.88%	99.58%	100.21%	95.56%	102.26%	101.46%	99.71%	97.20%	103.44%
3/7/2016	98.23%	102.25%	101.76%	96.20%	102.16%	106.64%	109.11%	97.14%	102.46%	98.95%	95.39%	104.15%	100.71%	100.71%	106.04%	104.63%
3/8/2016	96.80%	106.76%	103.03%	91.54%	102.71%	104.21%	103.38%	101.62%	109.38%	91.12%	95.48%	102.20%	102.95%	98.20%	101.80%	104.63%
3/8/2016	102.26%	102.80%	105.25%	95.72%	101.89%	105.87%	106.61%	103.31%	96.82%	106.53%	97.04%	102.84%	100.24%	102.04%	99.10%	104.35%

Dynamic IVS Positioning Repeatability

	Item1				Item 2				Item 3				Item 4			
Date	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4
11/17/2015	4.81	5.02	5.44	4.75	7.81	16.71	5.28	9.53	5.69	6.28	4.04	3.20	4.65	3.50	9.21	6.65
11/17/2015	11.48	8.12	3.58	1.61	5.00	4.31	8.52	7.25	4.12	3.77	8.41	7.05	2.80	3.01	3.67	1.84
11/17/2015	1.46	6.90	1.79	13.30	4.47	5.25	6.75	2.44	2.09	2.01	4.02	5.80	5.20	5.00	1.22	11.63
11/17/2015	6.84	6.46	4.94	6.65	0.00	5.49	8.78	5.55	9.61	7.09	4.69	16.15	3.77	1.56	1.70	6.71

	Item1				Item 2				Item 3				Item 4			
Date	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4
11/17/2015	9.94	8.41	5.10	7.60	4.47	8.92	8.79	6.10	3.03	4.10	7.07	8.86	9.80	6.00	14.31	21.64
11/17/2015	3.54	7.67	5.06	8.94	7.00	7.87	10.72	23.47	6.40	5.80	2.79	4.39	9.68	7.54	8.49	23.67
11/20/2015	9.44	12.01	14.01	18.95	3.00	8.59	22.64	21.12	2.44	3.44	2.44	8.48	15.05	13.51	15.38	7.22
11/20/2015	7.34	10.32	11.50	4.56	8.94	5.25	11.68	17.51	13.40	12.80	6.68	18.00	3.23	2.97	9.83	19.40
12/3/2015	9.61	11.40	11.06	15.98	11.18	7.67	1.98	4.40	4.53	6.53	6.10	4.39	13.84	4.00	19.84	16.55
12/3/2015	14.61	7.47	13.87	19.80	1.41	2.79	11.41	10.65	12.44	11.84	11.02	12.06	15.95	5.12	8.40	11.50
12/4/2015	14.02	13.73	18.95	14.21	1.00	4.71	10.42	8.66	4.51	7.47	5.95	2.69	3.23	3.35	6.98	8.59
12/4/2015	8.50	9.53	10.92	3.85	3.16	6.68	11.68	4.47	4.04	16.00	14.86	8.16	21.89	17.14	30.93	30.48
12/7/2015	10.56	10.22	9.81	15.81	14.32	8.77	10.94	9.81	6.71	7.09	12.27	7.00	20.06	7.94	12.23	21.73
12/7/2015	11.13	13.73	20.94	25.91	4.47	11.72	18.14	11.02	18.40	4.90	14.91	14.12	19.22	15.58	23.83	34.45
12/9/2015	10.30	10.88	7.91	12.88	6.17	12.12	18.30	5.17	10.21	6.96	8.46	21.34	8.75	5.25	12.50	22.96
12/9/2015	2.51	19.08	9.29	3.84	8.85	12.55	14.73	4.42	4.55	4.09	5.78	11.72	16.53	12.93	11.11	6.68
12/10/2015	1.77	1.22	14.65	9.74	20.00	7.73	14.33	12.60	2.44	3.09	6.05	3.67	19.32	15.10	17.07	15.35
12/10/2015	16.86	18.41	16.20	2.86	5.00	7.25	6.22	4.24	5.18	1.20	4.40	6.05	10.06	12.96	12.98	22.78
12/11/2015	9.69	8.77	9.51	16.92	11.62	5.21	1.27	8.39	5.16	4.18	4.37	8.47	9.89	8.03	15.50	8.24
12/11/2015	9.80	9.38	10.27	16.47	4.40	1.92	0.42	7.77	8.59	5.74	3.69	11.25	9.80	6.90	3.04	8.64
12/14/2015	9.28	9.13	13.91	20.87	10.31	4.76	7.77	3.31	13.68	12.11	4.18	15.37	4.31	0.52	8.26	15.23
12/14/2015	11.61	5.74	10.32	5.43	12.37	7.39	3.80	1.75	15.71	14.43	15.56	13.80	12.91	10.98	8.63	5.86
12/15/2015	15.78	14.54	17.96	8.51	17.80	3.97	11.72	8.28	7.40	5.80	5.60	17.02	3.56	8.77	12.53	9.40
12/15/2015	19.89	20.50	21.93	14.01	11.18	6.66	8.74	16.72	13.44	10.85	4.71	16.00	18.49	8.24	10.95	20.44
12/16/2015	15.61	15.53	8.10	14.48	24.70	18.71	12.41	6.68	17.40	15.80	5.02	16.04	13.84	10.07	12.74	20.83
12/16/2015	15.66	24.40	15.75	23.22	13.04	4.51	9.14	9.62	9.61	9.02	17.10	9.26	12.96	9.18	11.12	17.45
12/17/2015	22.94	15.40	15.16	20.80	11.57	6.17	9.39	18.27	15.91	14.39	22.60	16.46	19.20	9.21	15.18	23.48
12/17/2015	19.17	13.44	11.31	14.49	16.39	2.21	14.13	25.69	7.83	8.60	9.00	1.55	5.01	3.11	6.04	11.30
12/18/2015	10.26	13.61	20.81	10.71	17.33	24.89	23.73	24.26	11.44	10.70	6.70	15.02	15.96	13.86	12.97	8.20
12/18/2015	24.01	21.77	18.80	12.88	12.04	18.63	13.61	8.40	17.47	9.85	4.12	16.24	24.05	20.00	7.99	20.25
1/29/2016	2.41	5.28	2.28	3.88	6.20	10.47	12.63	5.66	1.08	5.20	4.00	6.61	2.79	2.67	0.89	0.63
2/3/2016	0.89	10.23	1.00	5.80	8.80	12.02	5.60	1.80	6.35	6.80	4.18	2.78	1.17	2.47	2.61	2.41
2/3/2016	6.28	6.20	5.81	17.57	11.80	5.53	7.44	0.80	7.47	1.44	1.28	3.65	4.77	4.28	4.22	4.82
2/4/2016	7.82	8.68	4.43	7.08	2.81	6.84	7.60	4.80	7.00	6.11	5.89	5.63	5.55	4.33	4.82	5.23
2/4/2016	6.84	4.39	6.96	2.84	14.37	20.85	18.44	12.56	3.31	5.56	5.57	9.48	3.54	3.76	2.72	2.68
2/5/2016	9.43	3.05	2.24	5.65	10.27	17.74	11.74	4.84	3.40	4.74	4.08	2.47	5.02	5.28	4.84	5.46
2/5/2016	1.61	7.52	3.22	1.44	3.11	9.18	3.69	5.20	6.90	2.34	6.00	4.42	6.10	5.84	3.49	3.79
2/8/2016	1.84	3.56	15.62	3.33	5.28	6.84	11.60	6.12	4.83	9.28	1.80	3.05	11.12	5.73	4.82	3.26
2/8/2016	4.94	7.79	3.49	4.57	6.11	4.00	2.41	8.86	2.04	4.64	5.12	5.56	6.90	7.97	0.63	1.87
2/9/2016	8.59	3.88	2.86	7.15	9.80	9.18	7.40	7.80	18.64	11.27	8.00	1.65	7.25	7.52	2.41	2.72
2/9/2016	5.88	5.20	4.56	7.84	6.58	4.94	5.69	1.28	5.33	8.14	3.23	6.75	3.60	3.94	6.21	6.83
2/10/2016	8.81	8.65	11.82	10.80	17.27	12.72	9.40	4.32	3.28	8.29	6.53	10.75	17.17	13.67	4.40	4.82
2/10/2016	5.10	6.80	5.88	4.20	6.68	8.21	6.08	7.21	5.69	7.80	2.01	10.49	0.60	6.37	16.41	20.94
2/11/2016	3.82	4.97	4.05	4.39	13.58	13.00	1.26	8.05	6.68	2.16	2.01	1.52	4.69	3.86	4.67	5.23
2/11/2016	6.08	3.88	6.45	8.80	4.25	7.00	13.69	6.51	7.07	5.66	2.42	3.54	8.38	7.25	3.61	3.69

	Item1				Item 2				Item 3				Item 4			
Date	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 1	Receiver 2	Receiver 3	Receiver 4
2/12/2016	18.40	11.20	9.63	16.82	9.80	7.72	3.12	4.39	17.46	17.57	9.05	15.61	18.16	13.81	12.81	5.81
2/12/2016	32.35	22.73	4.40	25.30	1.44	6.96	7.64	18.80	15.91	8.14	4.57	2.95	14.41	5.77	9.22	9.81
2/17/2016	18.05	11.45	7.38	9.37	8.49	8.06	7.40	13.74	16.43	9.23	6.00	10.61	11.03	11.48	5.46	5.66
2/17/2016	15.68	10.04	3.26	6.38	1.44	1.41	6.81	6.26	9.30	12.19	1.20	2.95	6.79	3.65	4.47	4.67
2/18/2016	2.72	3.98	9.04	3.96	6.68	12.71	5.69	1.28	4.04	4.89	5.20	5.28	5.49	5.28	9.88	8.99
2/18/2016	9.81	7.88	5.81	9.04	3.56	9.85	5.69	2.06	7.67	10.87	9.00	5.41	4.04	2.88	6.84	6.77
2/19/2016	18.44	13.22	7.33	5.34	6.93	10.63	17.20	4.39	3.06	4.74	4.10	2.47	6.16	1.71	2.86	3.69
2/19/2016	7.22	7.35	5.22	17.01	13.05	23.44	7.81	7.05	7.67	12.94	13.06	11.49	1.17	0.85	6.72	19.14
2/20/2016	1.84	0.82	6.65	2.34	10.20	8.88	9.81	1.56	2.60	0.82	3.10	0.85	8.12	0.57	3.85	4.23
2/20/2016	5.24	7.16	3.85	5.66	6.80	2.00	7.60	2.20	1.60	2.34	1.28	0.72	5.38	5.28	3.26	3.16
2/22/2016	5.44	7.53	7.00	11.99	17.34	15.92	12.43	6.28	8.46	1.22	10.38	2.13	3.97	3.54	4.40	3.79
2/22/2016	5.06	3.30	4.05	4.72	5.85	1.61	1.79	10.80	3.31	7.88	7.10	5.11	4.31	4.68	2.28	12.90
2/23/2016	11.84	8.66	2.00	6.32	4.37	4.22	9.81	6.53	2.79	1.22	4.08	0.85	1.17	1.71	4.47	4.60
2/23/2016	4.84	6.80	10.21	5.65	10.87	6.45	4.75	8.36	3.97	6.62	4.84	3.94	2.79	2.95	7.96	7.69
2/25/2016	3.26	2.55	6.02	4.74	6.68	2.53	5.46	0.80	7.55	3.81	1.20	5.77	6.16	5.84	5.10	8.21
2/25/2016	1.26	2.91	4.40	1.44	7.52	4.49	2.68	7.09	2.40	4.20	7.96	3.05	10.11	13.10	4.00	5.46
2/26/2016	13.93	7.08	5.69	2.34	0.82	8.60	2.00	11.97	2.09	5.34	4.88	2.13	21.06	16.68	6.08	7.00
2/26/2016	0.63	2.81	1.41	4.95	4.74	3.49	3.00	5.89	1.89	3.21	3.23	5.77	12.76	18.04	18.38	13.15
2/27/2016	2.61	3.81	8.60	1.44	4.97	5.53	4.94	4.84	3.31	5.05	2.33	2.95	16.21	13.85	10.81	11.88
2/27/2016	3.16	5.28	0.89	1.44	4.39	6.45	8.00	4.39	3.74	0.28	2.97	2.63	8.84	8.53	2.72	2.28
2/28/2016	21.06	17.98	19.44	15.36	12.86	4.05	12.46	2.80	3.84	5.65	2.15	9.42	22.01	17.86	9.65	9.67
2/28/2016	6.84	4.25	10.88	5.94	4.25	8.68	11.91	5.14	1.72	7.15	4.10	7.84	8.92	9.32	18.35	19.92
2/29/2016	2.00	1.97	9.77	5.85	18.02	7.62	1.61	10.85	10.45	13.34	11.00	3.05	16.39	14.22	10.74	11.19
2/29/2016	5.22	4.20	6.65	1.97	10.19	1.84	9.65	13.74	5.55	7.49	4.29	2.13	10.02	7.62	3.26	6.02
3/2/2016	2.68	0.82	2.41	0.82	7.80	1.34	4.40	5.20	2.60	7.79	3.10	0.85	12.47	11.13	8.22	8.54
3/2/2016	6.60	3.30	10.75	5.56	3.88	5.81	5.81	4.84	3.54	6.20	3.50	2.13	6.90	5.72	5.39	6.02
3/4/2016	1.41	2.81	3.61	8.88	12.98	8.21	6.81	11.49	7.40	8.88	9.88	6.09	10.10	8.61	0.63	0.89
3/4/2016	9.81	13.09	11.82	13.93	11.16	1.90	2.41	9.85	7.67	8.66	14.02	4.62	5.49	5.28	5.22	7.82
3/5/2016	10.75	13.47	9.04	6.58	7.35	2.41	3.61	6.14	17.15	9.25	1.20	5.77	8.77	7.34	8.51	6.65
3/5/2016	4.92	3.67	6.60	13.85	2.51	18.87	7.40	1.28	5.40	3.05	8.04	2.13	12.08	3.65	1.00	0.89
3/6/2016	4.92	2.16	4.92	3.30	7.52	4.49	10.14	3.23	3.40	2.34	5.06	0.72	12.01	9.62	5.81	6.23
3/6/2016	3.49	2.21	16.60	11.86	12.93	4.47	3.69	11.80	2.60	5.50	0.80	0.72	10.28	7.97	5.00	6.40
3/7/2016	8.82	10.88	10.20	15.56	5.13	12.34	7.40	1.28	5.76	1.22	8.20	0.85	6.46	6.09	5.46	5.81
3/7/2016	7.96	9.95	13.45	20.37	18.29	9.88	5.37	7.89	6.72	10.38	3.72	7.97	9.02	9.62	3.13	2.28
3/8/2016	4.49	9.23	8.40	2.51	4.95	13.00	6.45	1.80	10.59	6.46	3.23	2.13	4.02	2.67	5.00	5.44
3/8/2016	2.68	0.82	11.66	2.84	9.87	3.26	10.32	4.84	7.55	6.58	3.93	4.44	7.47	8.03	5.53	6.26

APPENDIX C POLARIZABILITY LIBRARY ENTRIES

Dig Type	Identification	Length (m)	Library ID	UXA_SIZE_14
TOI	105mm HEAT	0.64	105mm heat_BP110413_TP24m	1.459
TOI	105mm HEAT	0.47	105mm heat_BP110826_TP56m	1.103
TOI	105mm HEAT	0.47	105mm heat_BP110826_TP56s	1.251
TOI	105mm HEAT	0.47	105mm heat_BP110826_TP57m	0.581
TOI	105mm HEAT	0.47	105mm heat_BP110826_TP57s	0.9
TOI	105mm HEAT	0.47	105mm heat_BP110826_TP58s	1.534
TOI	105mm HEAT	0.47	105mm heat_BP110826_TP59s	1.461
TOI	105mm projectile	0.47	105mm proj_BP110826_TP49s	1.41
TOI	105mm projectile	0.47	105mm proj_BP110826_TP50m	1.264
TOI	105mm projectile	0.47	105mm proj_BP110826_TP50s	1.508
TOI	105mm projectile	0.47	105mm proj_BP110826_TP53s	1.587
TOI	155mm projectile	0.79	155mm projectile_SR2515s	2.033
TOI	155mm	*	155mm_CE2048m	1.778
TOI	155mm	*	155mm_CE2135m	1.875
TOI	155mm	*	155mm_CE42507m	1.666
TOI	155mm	*	155mm_CE52161	1.665
TOI	155mm	*	155mm_CE62282	1.731
TOI	155mm	*	155mm_MMRIVS_10002	2.096
TOI	2.36in rocket	*	2.36in rocket_EL_TP17s	0.855
TOI	2.36in rocket	*	2.36in rocket_EL_TP24s	0.83
TOI	2.36in rocket	*	2.36in rocket_EL_TP2s	0.797
TOI	2.36in rocket	0.5	2.36in rocket_FR_TP23s	1.172
TOI	20mm	*	20mm_BP111103_TP18s	-0.547
TOI	20mm M55 Projectile	0.08	20mm_BP111103_TP2s	-0.577
TOI	20mm	*	20mm_BP111103_TP36s	-0.522
TOI	20mm	*	20mm_BP111103_TP4s	-0.295
TOI	37mm projectile	0.12	37mm projectile_SR1781s	0.328
TOI	37mm	0.11	37mm_2011LSBP840m	-0.088
TOI	37mm	0.11	37mm_2011LSBP840s	0.288
TOI	37mm	0.11	37mm_BE365s	-0.24
TOI	37mm	0.12	37mm_BE534s	0.393
TOI	37mm	0.11	37mm_BE668s	0.259
TOI	37mm	0.11	37mm_BE670s	0.182
TOI	37mm	0.11	37mm_BE74s	0.221
TOI	37mm	0.11	37mm_BE754s	0.528
TOI	37mm projectile	*	37mm_BP110413_TP18s	0.233
TOI	37mm projectile	0.11	37mm_BP110826_TP10s	0.129
TOI	37mm projectile	*	37mm_SR_IVS2s	0.106
TOI	37mm	*	37mm_SWPG_TP4s	-0.082
TOI	3in projectile	*	3in proj_BP110826_TP73s	1.159
TOI	3in projectile	*	3in proj_BP110826_TP80s	1.016
TOI	3in projectile	*	3in proj_BP110826_TP81m	0.867
TOI	3in projectile	*	3in proj_BP110826_TP81s	1.141
TOI	3in stokes mortar	0.36	3in stokes mortar_SR2227s	1.236
TOI	3in stokes mortar	0.36	3in stokes mortar_SR2609s	1.379
TOI	4.2in projectile	*	4.2in Proj_RSA_TS18	1.564
TOI	40mm grenade	0.08	40mm gren_BP110427_TP20s	-0.073

Dig Type	Identification	Length (m)	Library ID	UXA_SIZE_14
TOI	40mm training cartridge.	*	40mm_2011LSBP1325s	-0.017
TOI	40mm training cartridge.	*	40mm_2011LSBP1344s	-0.109
TOI	40mm training cartridge.	*	40mm_2011LSBP2913s	-0.047
TOI	40mm	*	40mm_SWPG_TP1s	0.281
TOI	57mm	*	57mm_SWPG_TP2s	0.777
TOI	57mm	*	57mm_SWPG_TP7s	0.677
TOI	5in projectile	*	5in proj_BP110826_TP74s	1.834
TOI	5in projectile	*	5in proj_BP110826_TP75s	1.554
TOI	5in projectile	*	5in proj_BP110826_TP77m	1.618
TOI	5in projectile	*	5in proj_BP110826_TP77s	1.662
TOI	5in projectile	*	5in proj_BP110826_TP78m	1.703
TOI	60mm mortar body	0.13	60mm body_BP110427_TP51s	0.611
TOI	60mm HE M49A3	*	60mm_29P_TP118s	0.676
TOI	60mm HE M69 - rusty, missing nose cone and hollow	*	60mm_29P_TP122s	0.647
TOI	60mm HE M69	*	60mm_29P_TP51s	0.855
TOI	60mm HE M69 without tail boom	*	60mm_29P_TP53s	0.67
TOI	60mm mortar body	0.13	60mm_BP110826_TP16s	0.785
TOI	60mm mortar body	0.13	60mm_BP110826_TP18s	0.823
TOI	60mm mortar short	0.25	60mm_BP110826_TP22m	0.528
TOI	60mm mortar short	0.25	60mm_BP110826_TP22s	0.733
TOI	60mm mortar short	0.25	60mm_BP110826_TP23m	0.699
TOI	60mm mortar short	0.25	60mm_BP110826_TP26s	0.7
TOI	60mm mortar long	0.31	60mm_BP110826_TP29s	0.823
TOI	60mm mortar long	0.31	60mm_BP110826_TP33m	0.262
TOI	60mm mortar long	0.31	60mm_BP110826_TP33s	0.786
TOI	75mm	*	75mm_CE3022m	1.12
TOI	75mm projectile	*	75mm_SR_IVS3s	1.081
TOI	81mm illumination	*	81mm illumination_RSA_TS15	1.292
TOI	81mm HE M69	*	81mm_29P_TP54s	1.263
TOI	81mm	0.49	81mm_BE2m	1.12
TOI	81mm	0.48	81mm_BE527s	1.286
TOI	81mm	0.48	81mm_BE742s	1.286
TOI	81mm	0.48	81mm_BE903s	1.424
TOI	81mm mortar complete	0.5	81mm_BP110413_TP21s	1.292
TOI	81mm mortar complete	0.5	81mm_BP110826_TP36s	1.144
TOI	81mm mortar complete	0.5	81mm_BP110826_TP37s	1.196
TOI	81mm mortar complete	0.5	81mm_BP110826_TP46s	1.032
TOI	81mm	*	81mm_MMRIVS_10003	1.361
TOI	Aluminum rifle grenade	*	Aluminum rifle grenade_EL_52s	0.164
TOI	Aluminum rifle grenade	*	Aluminum rifle grenade_EL_TP45s	0.206
TOI	Fuze Component	0.05	Fuze Component_BE697s	-0.48
TOI	Fuze Part	0.05	Fuze Part_BE196s	-0.666
TOI	Fuze Part	0.06	Fuze Part_BE76s	0.013
TOI	Fuze Part	0.05	Fuze Part_BE805s	-0.666
TOI	Fuze Piece	0.05	Fuze Piece_BE482s	-0.451
TOI	large ISO	*	large ISO_SWPG_IVS5s	1.598
TOI	large ISO	*	large ISO_SWPG_TP1s	1.544
TOI	M83 smoke hand grenade	*	M83 smoke grenade_RSA_TS12	0.66
TOI	Medium ISO	*	MED_ISO_MMRIVS_10005	0.931

Dig Type	Identification	Length (m)	Library ID	UXA_SIZE_14
TOI	medium ISO80	0.2	medium ISO80_SR2653s	1.008
TOI	medium ISO	*	medium ISO_SWPG_TP2s	0.978
TOI	MK2 hand grenade	0.11	MK2 Hand grenade_EL_TP87s	0.295
TOI	MK2 hand grenade	0.11	MK2 Hand grenade_FR_TP3s	0.317
TOI	Rifle grenade	*	rifle grenade_EL_73s	0.492
TOI	Rifle grenade	0.25	rifle grenade_FR_TP17s	0.615
TOI	Rifle grenade	0.25	rifle grenade_FR_TP18s	0.697
TOI	Rifle grenade	0.25	rifle grenade_FR_TP4s	0.787
TOI	small ISO80	0.1	small ISO80_FR_IVS2	0.222
TOI	small ISO80	0.1	small ISO80_SR_IVS5s	0.472
TOI	Small ISO	0.1	Small ISO_BE305s	0.359
TOI	Small ISO	0.1	Small ISO_BE460s	0.252
TOI	Small ISO	0.1	Small ISO_BE622s	0.137
TOI	Small ISO	0.1	Small ISO_BE_IVS2005s	0.213